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MOVING STRIATIONS IN A VERY LOW CURRENT NEON GLOW DISCHARGE

DONALD F. PANZER
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MOVING STRIATIONS IN A VERY LOW CURRENT NEON GLOW DISCHARGE

by

Donald F. Panzer
Captain, United States Army

and

Richard F. White
Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS

United States Naval Postgraduate School
Monterey, California

1963

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ABSTRACT

Moving striations in a direct current glow discharge were studied in neon over a pressure range of 10.1 mm to 50 microns of mercury and a current range of 7 to 0.01 milliamperes. Tubes of constant diameter, one of 2.54 cm, another of 0.55 cm, were used.

Regions, normally at pressures less than 8 mm and currents less than 1 ma, were found in which no striations were evident either in photomultiplier traces on an oscilloscope or in rotating mirror observations. Further reductions of current to regions of 0.5-0.1 ma brought a return of striations, particularly in the smaller diameter tube. These striations exhibited much higher frequencies and velocities than those in the higher current range.

An investigation was conducted to determine the limits of the striation free regions in each tube and striation stability in adjoining areas. Although a similarity is noted between striation parameters in the two tubes, there is no simple relationship between tube diameters nor between the striation parameters of the individual tubes.

In the regions of instability a wave was noted which appeared to be travelling in the opposite direction and at a much greater velocity than the positive moving striations. This wave, though evident in rotating mirror observations, was undetectable with the photomultiplier tube.

ACKNOWLEDGEMENT

The writers express their sincere appreciation to Professor Norman L. Oleson for his continued interest and guidance throughout these investigations; to Professor A. W. Cooper for his suggestions and assistance with the experimental equipment, and to the technicians of the Physics Department for their assistance and advice - John Calder, Raymond Garcia, Kenneth Smith, and Robert Moeller.

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1.0 Introduction

1.1 History

Since the discovery of standing striations, stationary luminous waves visible to the naked eye, in a glow discharge by Abria in 1843 /1/ and moving striations, the term applied to these alternate light and dark regions moving through the positive column, usually from the anode toward the cathode, about 30 years later, /2/ many studies have been made of the subject, theoretically and experimentally. Interest has been especially keen during the past several decades. With the great strides forward in the fields of science during this period, especially electronics, it was only natural that advantage should be taken of the improved experimental techniques and equipment to attack the problem of explaining this phenomenon.

Much data have been taken. However, as the amount of data increased, so did the size of the problem as the investigators realized the tremendous effects of the varying parameters on the results obtained. Tube dimensions, current, voltage, pressure, type of gas, electrode configuration and material, and temperature all contribute to produce varying results. Except for extensive investigations by individuals and communications between investigators, we should now find ourselves in the position of the blind men examining the elephant. Nevertheless, despite many theoretical attempts

to explain the existance and properties of moving striations, no adequate theory exists.

1.2 Characteristics of a Glow Discharge

The characteristic features of the glow discharge are shown in Figure 1. Von Engle /3/ describes this discharge as one in which electrons are emitted by the cathode as it is bombarded by particles and light quanta from the gas. When a voltage is applied across the discharge tube, the current, which flows through the gas at a pressure of several millimeters, produces a nearly uniform glow throughout the tube. The variations of this glow are dependent upon the previously mentioned parameters. Emeleus /4/ presents an excellent outline of the main phenomena of the glow discharge emphasizing the complex nature of gaseous conductors.

1.3 Previous Theoretical Work

A theory explaining the presence of moving striations and predicting their behavior still awaits formulation. However, the large variations in striation parameters determined by experiment and the complexity of the differential equations has hindered the formulation of any adequate theory which accounts for the known experimental facts.

In the late 1940's Donahue and Dieke /5/, interpreting their experimental work, stated that oscillations and moving striations are not exceptional cases, but are normally present within a large range of pressures and current "whenever

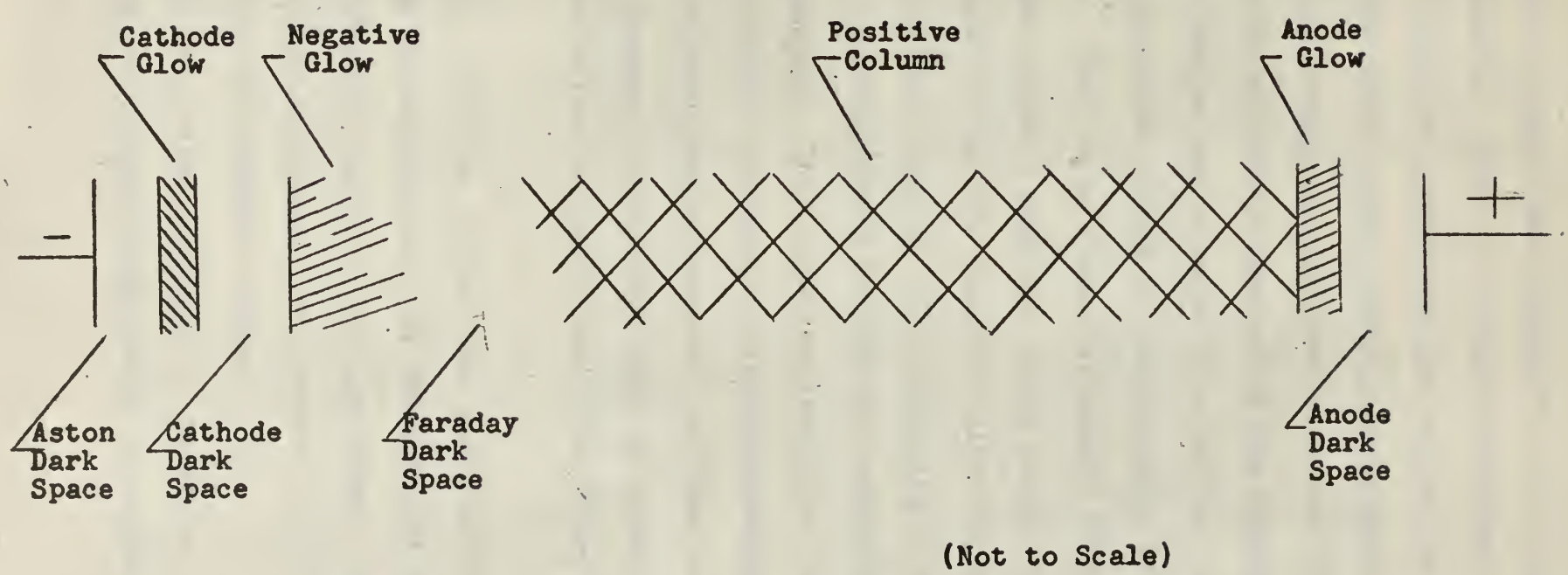


Figure 1. A Glow Discharge [3]

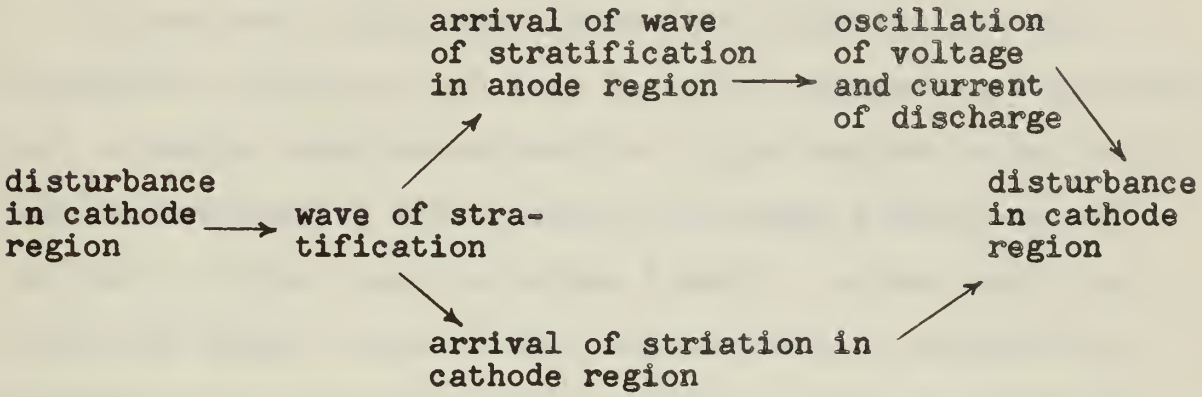
a positive column exists", and therefore it is expected that they play an essential part in the glow discharge. A cycle is discussed. Positive striations are regions of high positive space charge which travel toward the negative glow. When the positive striation, followed by a high field region, comes close to the electrons trapped in the negative glow, the barrier is lowered and a burst of electrons is emitted as a negative striation moving in the opposite direction toward the anode. When these electrons depart from the negative glow, they leave behind a positive space charge which moves toward the cathode through the negative glow raising the potential in the cathode region. The resulting flow of electrons from the cathode travels across the cathode dark space as a negative striation. This negative striation, in turn, meets the oncoming positive striation at the cathode edge of the negative glow, neutralization occurs, and electron entrapment begins again. However, they state that it remains to say how the positive striations arise in the first place near the anode.

Zaitsev /6/, in 1951, states that oscillations in the discharge cause the striations; the oscillation sources being localized in different parts of the discharge. The positive column disturbances originate from sources in the anode area or in the head of the positive column.

About this same time, Gordeev /7/ described positive striations as a wave group initiated by electrons changing

velocity in the anode fall and negative striations as reflections of the positive striations in the negative glow or at the cathode.

In 1954 Pekarek /8/ proposed two mechanisms for the self excitation of low frequency oscillations connected with moving striations:


arrival of wave of stratification in anode region
oscillation of voltage and current of discharge
disturbance in cathode region
wave of stratification
disturbance in cathode region
arrival of striation in cathode region

These two feedback loops initiate two types of waves of stratification; fast and slow. The fast waves, he believes, result from direct ionization of atoms by electrons; the slow waves from stepwise or cumulative ionization. In this paper he described transient processes, artifically induced by a small external perturbation, that showed, in his opinion, that moving striations in inert gases are produced by the periodic repetition of characteristic waves propagating from the cathode to the anode. These "waves of stratification" provide the link that he considered to be essential in the chain of processes by which the feedback loop is closed in the two mechanisms.

The following year Watanabe and Oleson /9/ showed that

there can exist in the positive column, travelling waves of both ion density and electron density, but felt it would be premature to identify these waves with moving striations. This differed from previous papers by other authors using the diffusion equations where only electron density was considered or electron and ion density equality was assumed.

Robertson in 1957 /10/ showed that when the ion and metastable production and loss rates are related in a plausible way, a stable homogeneous positive column may not exist at all, and the instability which results in moving striations may originate in the positive column itself. He uses small perturbation theory, which along with the lack of reliable expressions for ionization and excitation rates, he considers the most important weakness of his striation theory.

Shortly after Robertson's paper /10/, Yoshimoto, Sato, and Nakao /11/,/12/ proposed that moving striations resulted from a light intensity wave which travels toward the cathode changing its amplitude and velocity; the velocity being different from the striation velocity. This wave results from the interaction between an electric field intensity wave moving towards the cathode and an electron density wave which modulates the preceeding wave periodically. Moving striations and standing striations are believed to be the result of this interaction.

In the late 1950's Pekarek /13/,/14/ presents several theoretical papers based on his earlier "wave of stratifica-

tion" concept, emphasizing this transient process as the basic phenomen in the production of moving striations. Each striation is composed of two relatively independent regions of the positive and negative space charge. The wave of stratification he interprets as the gradual microscopic polarization of the plasma of a positive column, the creation of characteristic "domains" with alternately positive and negative space charges.

Pekarek /13/, confining himself to the processes of production and decay of individual striations, believes that the transient process is a much more exact guide than the stationary state in that in the former there are five microscopic measurable parameters compared to only two independent parameters for the latter, i.e.; the velocity of propagation of the wave of stratification from cathode to anode, spatial period of stiations, lifetime of nth striation, and the ratio of maximum amplitudes of neighboring striations versus the spatial period of the striations and the velocity of movement of the striations. He also states that other important properties of the transient process with small perturbation is its linearity and the fact that it depends only on the state of the plasma of the positive column itself.

In a later paper he further states /14/ from analysis of his mechanism of feedback, the factors affecting the self-excitation of low-frequency oscillations and the production of moving striations are:

1) The tendency of the plasma to stratification.

2) The length of the positive column.

3) Processes in regions at the electrodes.

4) The external electric circuit.

In 1961 Pekarek and Krejci /15/ presented their explanation of the physical nature of moving striations in a d.c. discharge plasma. They base their interpretation on the mathematical expression of the production of a periodic structure in plasma after an aperiodic disturbance. In this they include terms related to only three basic phenomena occuring in the plasma of each d.c. discharge: a) the dependence of the rate of ionization on the electron temperature and hence, the electric field, b) the production of space charges due to the different rates of diffusion of the electrons and ions, c) the creation of additional electric fields due to the creation of space charges. The interactions of these phenomena give rise to a chain, expanded in time and space, which leads to the production of moving striations. In concluding their direct solution of the basic equations for an aperiodic initial condition, they state that their theory does not explain the time properties of the wave of stratification, nor does it solve the question of amplification and damping of the wave of stratification. Nevertheless, the determination of the decisive physical processes which lead to moving striations and the explanation of the basic mechanism of their successive production they consider valued results of this

theory.

In 1962 Pekarek and Krejci /16/ published several more theoretical papers. The mechanism of the amplification of moving striations in a d.c. discharge is discussed. Previous theoretical papers by various authors, they state, have neglected amplification by assuming a stable state in which the amplification in space and time is zero. However, the amplitudes of the striations along the length of the tube are equal only when they are large. Hence, they attempt to explain the existence of amplification within the framework of the linear uni-dimensional theory and by means of basic general processes occuring in any plasma of a d.c. discharge. This shows, they state, that the only phenomenon which can lead to amplification of the striation of a positive column is the space shift of the temperature curve of the electrons with respect to the course of the electric field. This space shift is caused by the fact that the temperature of the electrons in a region is not given only by the local intensity of the electric field in that region, but also depends to an extent on the potential difference through which the electrons passed previously. The concept of the mechanism of amplification is, then, that at the point of maximum ion concentration the deflection of the temperature of the electrons from the equilibrium value is positive and can, by increased ionization, cause a further increase in the amplitude of the maximum. They omit processes which are not absolutely necessary to explain amplification

to facilitate the mathematical solution although realizing that doing so will result in disagreement between theoretical and experimental results. However, when numerical values are substituted in the resulting equations, there is an order of magnitude agreement.

Pekarek, /17/ discusses time production and spatial distribution of macroscopic space charges in a d.c. discharge plasma. It is his purpose to calculate the time and space changes in the macroscopic space charges and electric fields in the plasma of a positive column caused by the fact that the axial homogeniety of the positive ion distribution is disturbed at some place in the plasma. This interest is aroused by the connection of these changes with the striations (moving and standing) in a positive column.

Finally Pekarek and Krejci /18/, although pointing out the deficiencies of past theoretical papers, their own and others, draw on the situation which these papers create and using new experimental data, begin what they believe is the final solution to the whole problem. Emphasizing the physical side of the problem, they seek to lay a basis for the microphysical theory of moving striations by deriving a basic partial integro-differential equation in a general form and using its general solution. Although this solution is not suitable for direct quantitative comparison with experiment, they plan to publish future papers that will contain a suitable approximate solution. With the buildup of this theory, they hope to

explain the simultaneous existence of several types of striations and other specific properties of them by including in the theory other specific processes which have been neglected.

1.4 Previous Experimental Work

Some experimental work was reported toward the end of the 19th Century and the first quarter of the present century, but it was Pupp /19/ in the early 1930's who conducted the first large scale investigation. He reports his technique of measuring striation parameters using photocells and an oscilloscope. Later /20/ he discusses the disturbances noted by variations of parameters such as the shape of the discharge tube and the frequency of moving striations as a function of pressure. Later publications /21/ describe measurements using probe and oscillographic techniques.

It was not until about fifteen years later that the next extensive experimental report appeared; this by Donahue and Dieke /22/. Here they reported in detail their study of the properties of the electrical and light intensity oscillations in argon glow discharges which was carried out using a photomultiplier tube and an oscillograph. Results were reported concerning the dependence of the frequency, velocity, and wavelength on the current and pressure.

Zaitsev, /6/,/23/ about this time, states that he was able to affect and even wipe out moving striations by placing certain tube regions in a magnetic field. His second paper

concerning conditions for natural oscillations and moving striations describes a region in which beats are created. Here he has found a second system of moving striations with the frequency of the beats. He also reports producing moving striations using an oscillator frequency which influences the striation velocity.

Oleson and Cooper have published several papers concerning their experimental results. The first /24/ reports the effect on the frequency of altering the anode-cathode distance in the tube. It appeared to be generally a periodic function of the anode-cathode distance; the greatest effect being caused by the cathode movement. In a more recent paper they report /25/ the results of the investigation of the upper limits of the striated regime and the critical currents determined. Using a sectioned tube of various diameters, they were able to determine the effect of tube diameter on critical current. Their experiments also indicated that striations can exist in a region isolated from the electrodes by striation free regions; an oscillating anode fall region is not necessary for the presence of striations; and a striation pattern, probably similar to Pekarek's "wave of stratification", moving from cathode to anode may be observed only near cutoff.

Coulter, in 1960, /26/ also gives a detailed account of his experimental work concerning the negative sections of moving striations in a neon discharge. Among them is also an investigation of the upper limits of the striated regime where

he too found that striations disappear beginning first at the cathode and finally from the entire column as the current is varied. His observations seem to show that the striations are largely a phenomenon originating at the anode end of the column and that they do not normally affect the Faraday dark space.

Cooper /27/ has also investigated the influence of the anode on moving striations in argon; in particular, the assertion by some authors that oscillation in the anode glow is the source of moving striations. He found that the anode spots and voltage oscillation remain virtually unchanged as the striations disappear and for currents above the critical value. From this it is concluded that the presence of oscillating anode spots is not a necessary condition for the existance of moving striations in argon.

2.0 Experimental Procedures and Equipment

2.1 Vacuum System

A schematic diagram of the vacuum system is shown in Figure 2. The system was designed by A. W. Cooper and constructed by J. Calder. The system is extremely flexible in that tube changes can be made with a minimum of effort, and with a minimum of contamination. In addition, the construction of the system affords ease in bake-out procedures.

2.2 Vacuum Techniques

Evacuation of the system was accomplished by means of a Consolidated Vacuum Corporation two-stage oil diffusion pump and a Welch Manufacturing Company fore pump. With the additional aid of two liquid nitrogen traps, these pumps were capable of attaining pressures well into the 10^{-7} mm of mercury range. Vacuum pressures were measured by means of a Consolidated Electro-dynamics Corporation ionization guage circuit type GIC-110, in conjunction with a VG1A sensing tube. An electric alarm circuit was incorporated into this system in order to protect the VG1A tube in case of a sudden loss of vacuum. This alarm system proved its usefulness on several occasions. Gas pressures were measured by means of a standard U-shaped manometer filled with Octoil-S diffusion pump oil.

In order to achieve a high purity discharge, the tube was baked at a temperature approaching 400°C for periods of twelve

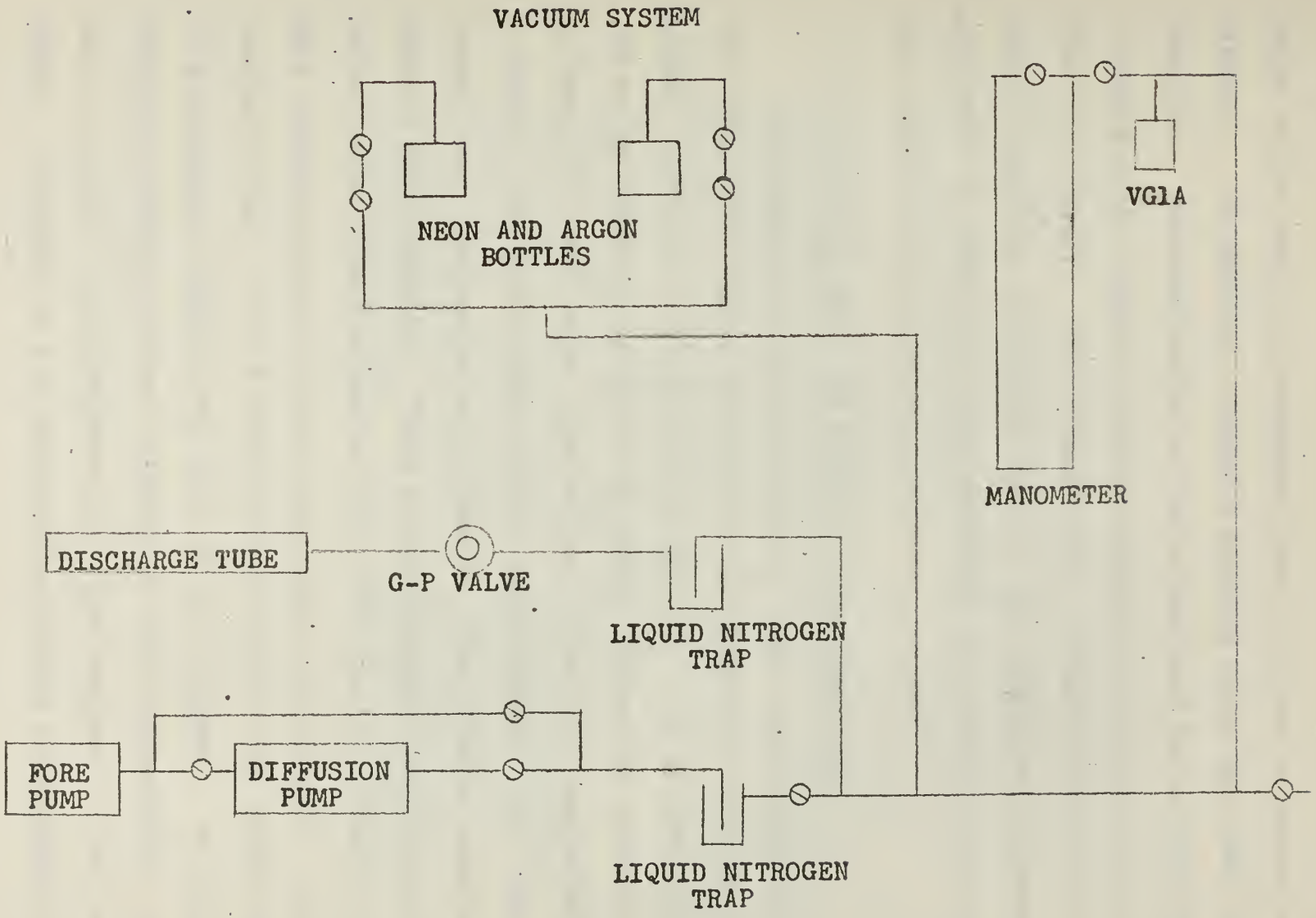

VACUUM SYSTEM
NEON AND ARGON BOTTLES
VG1A
MANOMETER
DISCHARGE TUBE
G-P VALVE
LIQUID NITROGEN TRAP
FORE PUMP
DIFFUSION PUMP
LIQUID NITROGEN TRAP

Figure 2

hours in a portable, thermostatically controlled oven. A photograph of the partially assembled oven in place is shown in Figure 3. In addition, standard heating tapes were used when required. Decontamination of the electrodes was accomplished by means of an induction heater manufactured by the Scientific Electric Company. The filaments were cleaned by means of resistive heating. The final step in the purification process consisted of igniting a neon discharge and slowly evacuating the tube until the discharge was extinguished.

2.3 Discharge Tube and Electrode Configuration

Two discharge tubes were used in these investigations. The first tube studied was 2.54 cm in diameter and 86 cm in length (hereafter referred to as Tube I). The second tube was .55 cm in diameter and 89 cm in length (hereafter referred to as Tube II). Both were constructed in the tube laboratory by J. Calder, the Postgraduate School Glass Blower. All electrodes were constructed by R. Moeller, the Physics Department machine shop operator. These electrodes were basically patterned after those designed by Pupp /28/ who used them to eliminate positive anode fall and associated oscillations. In the assembly itself, 10 mil tantalum was used for the sleeve while 10 mil annealed tungsten was used in the filament. An all-metal Granville-Phillips valve, bakeable in the oven assembly, was used to isolate the discharge tube from the rest of the vacuum system. Diagrams of the tubes and electrode configuration are

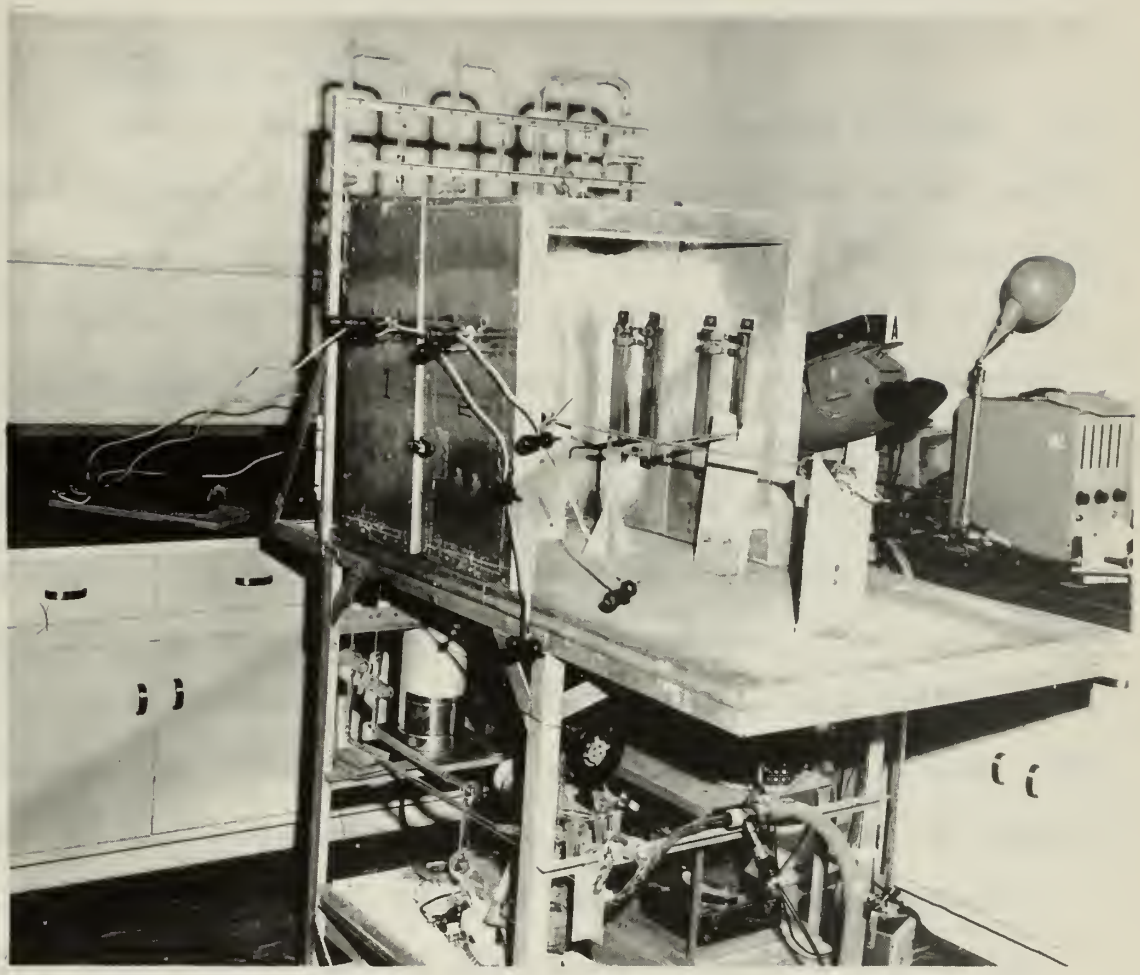


Figure 3 - Partially assembled oven in position.

are shown in Figure 4. In this system, either electrode could be utilized as anode or cathode. (Note: Tube II was constructed with a probe at the center of the tube as shown in Figure 4. The probe was not used in this investigation.)

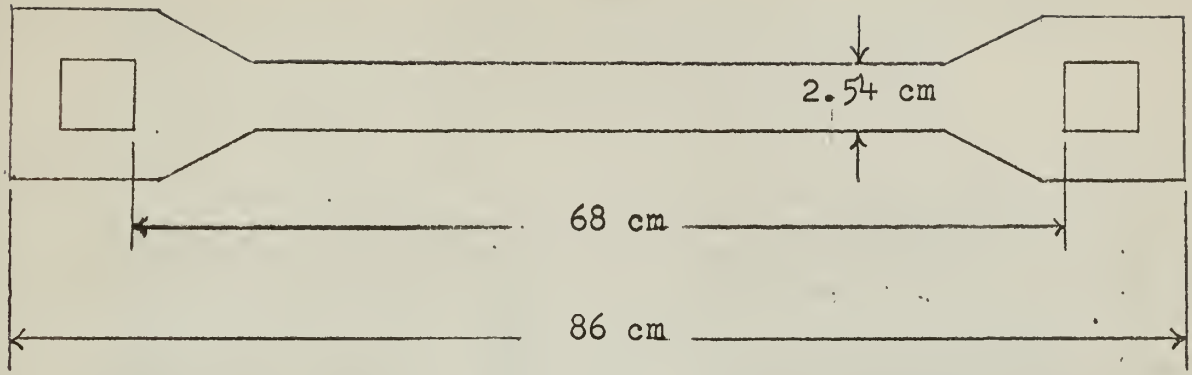
2.4 Electronic Circuit

In order to be able to investigate the low pressure, low current regions of the discharge, a high voltage power supply was utilized along with very high resistance. The power supply used for this region was an NJE Model HA-51 with a range of 0-10 ma and 0-30 kv in conjunction with resistance of up to 22.5 megohm. In the higher amperage range (1-10 ma), two power supplies connected in series with a variable resistor were used. The two supplies used were a General Electric Model YPD-4 with a range of 0-150 ma and 0-1.5 kv, and a Kepco Labs Model 1250B with a range of 0-500 ma and 0-1 kv. The resistance for this region was variable from 0-3.21 meg. The basic schematic diagram of these circuits is shown in Figure 5.

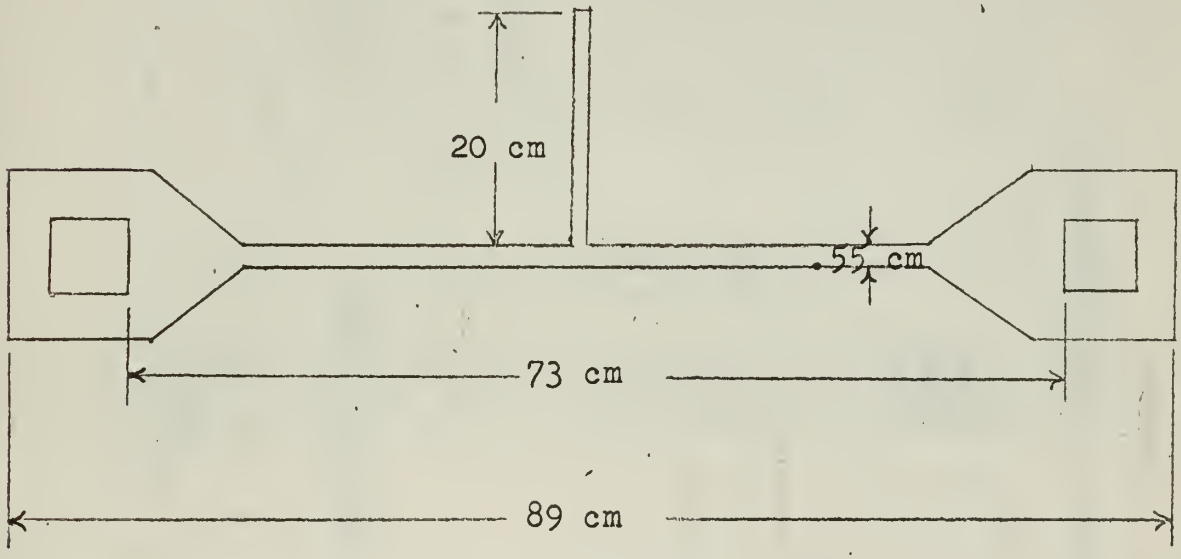
The Pupp Anode was used at various stages in these investigation from 50-120 ma with no noticeable effect. The power supplies used were a locally produced model with a range of 0-500 volts, and a Kepco Model 236-15A with a range of 0-15 amps and 0-50 volts.

2.5 Measuring Equipment

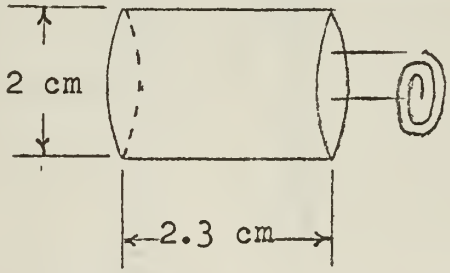
Photographs of the experimental equipment are shown in Figures 6 and 7. The parameters of the neon discharge were



Discharge Tube I

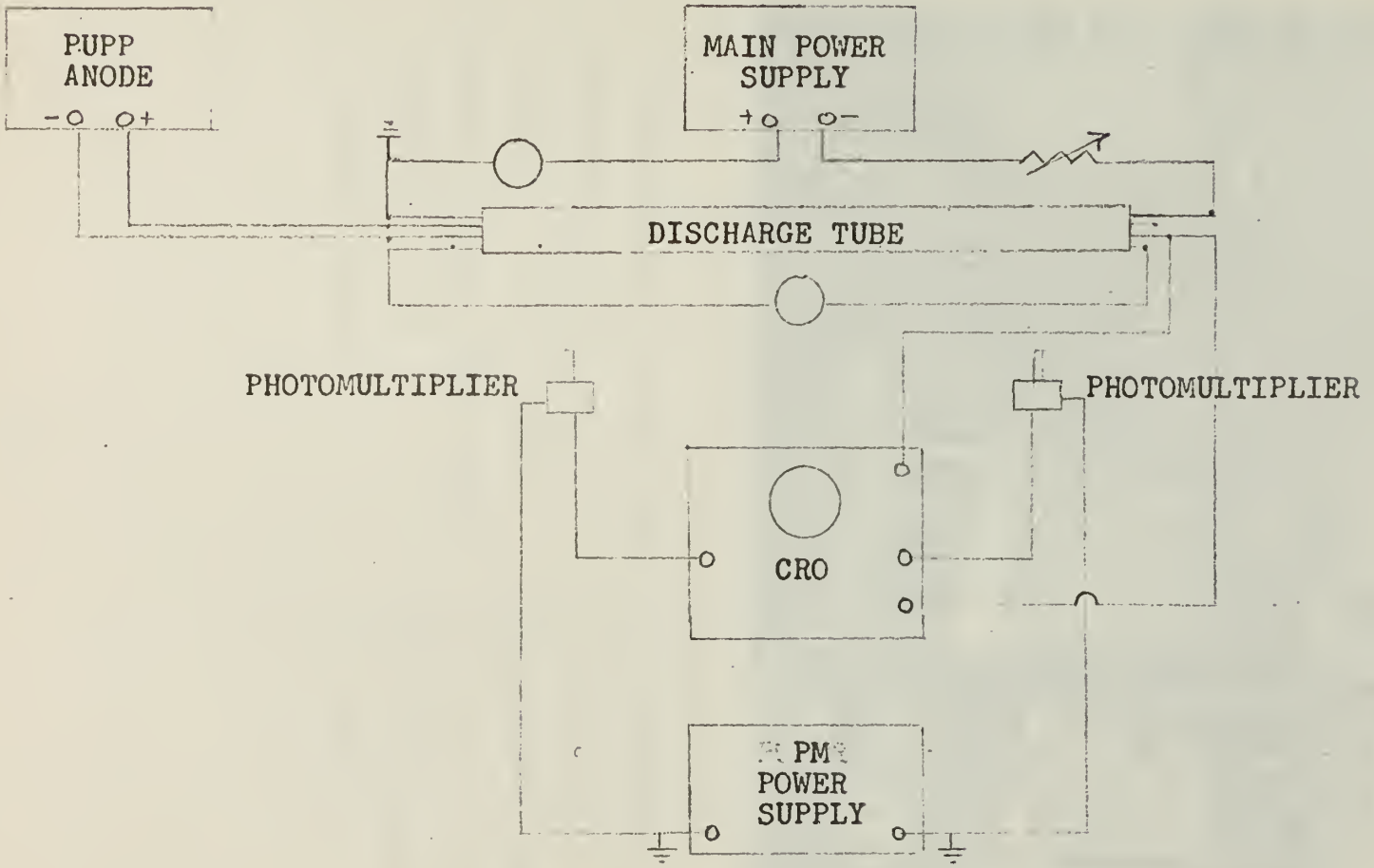


Discharge Tube II



Electrode Configuration

Figure 4



ELECTRONIC CIRCUIT SCHEMATIC

Figure 5

Figure 6 - General view of experimental equipment.

A. Photomultiplier power supply
B. Pupp anode power supply
C. Pupp anode power supply
D. Main discharge power supply
E. Rotating mirror
F. Polaroid camera
G. Decade amplifier
H. Mirror RPM counter
I. GIC-110 power supply
J. Oscilloscope camera
K. Photomultiplier tube
L. Resistors

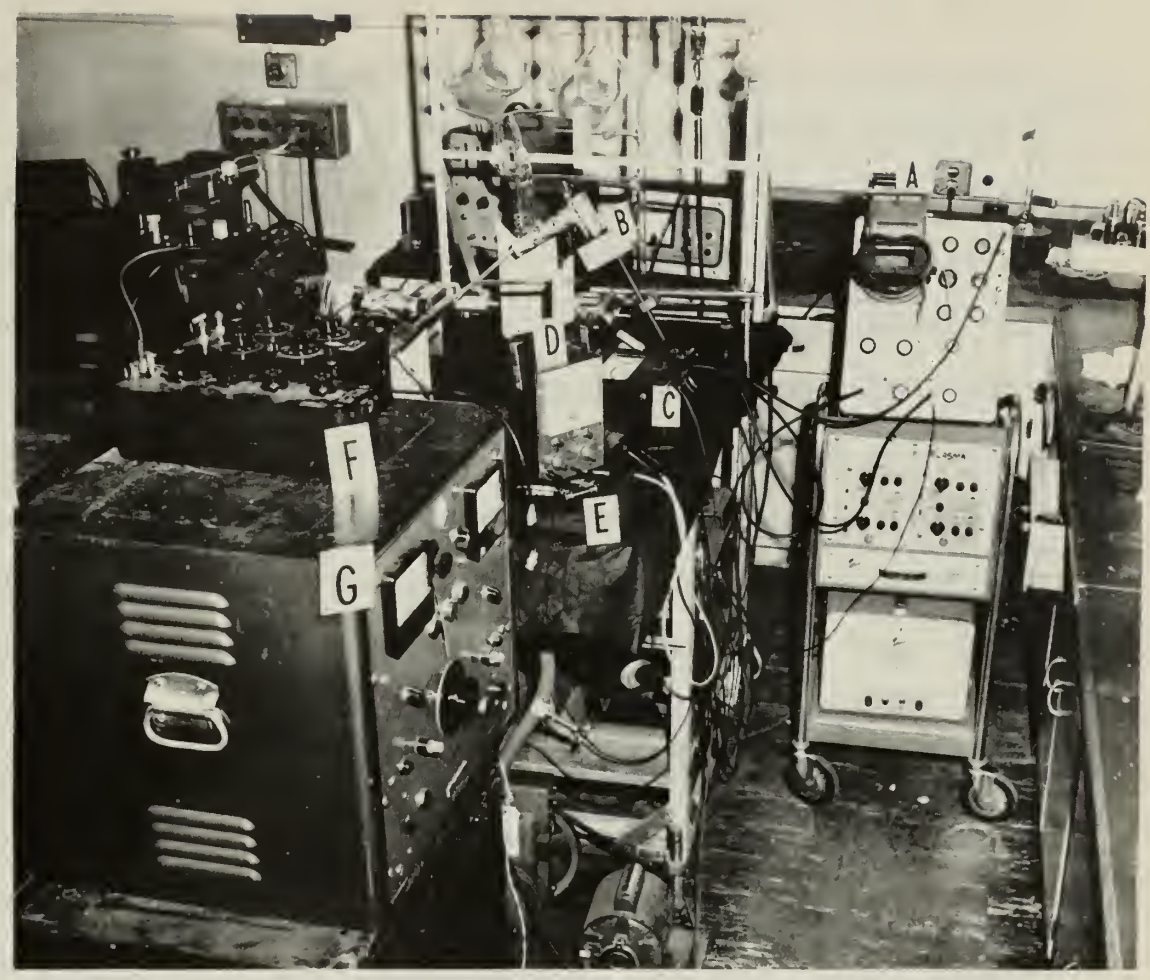


Figure 7 - General view of experimental equipment.

A. Oscilloscope
B. Photomultiplier tube
C. Ammeter
D. Voltmeter
E. High resistance
F. Variable resistance
G. Main discharge power supply

measured with a milliameter, voltmeter, oscilloscope, and rotating mirror. The milliameter used was a Weston Model 622, which had the advantage of being able to measure currents varying from 0-1000 ma without having to interrupt the electrical circuit to change scales. Discharge tube voltage was measured by an RCA-WV-77E voltmeter. A Tektronix Model 551A Dual-Beam Oscilloscope in conjunction with an RCA 1P21 photomultiplier tube was used to measure amplitude and wavelength of moving striations when the discharge was stable. Frequency was also obtained from these data. When the discharge was not stable, velocity and wavelength measurements were obtained from rotating mirror photographs. A photograph of the rotating mirror and associated camera equipment is shown in Figure 8. The mirror is made of stainless steel with dimensions of 4"x6"x1". One surface of the mirror is polished and is coated with a thin film of aluminum. The mirror can be driven at speeds varying from 0-9250 revolutions per minute. Speed of the mirror was determined by means of a Hewlitt Packard 521A electronic counter.

2.6 Wavelength Measurement

The wavelength of stable moving striations was measured by means of the photomultiplier tube. The sweep was triggered externally by the discharge tube voltage oscillation. The output of the photomultiplier tube was displayed on the oscilloscope. As the photomultiplier tube is moved along its track, the striation trace goes in and out of phase with the

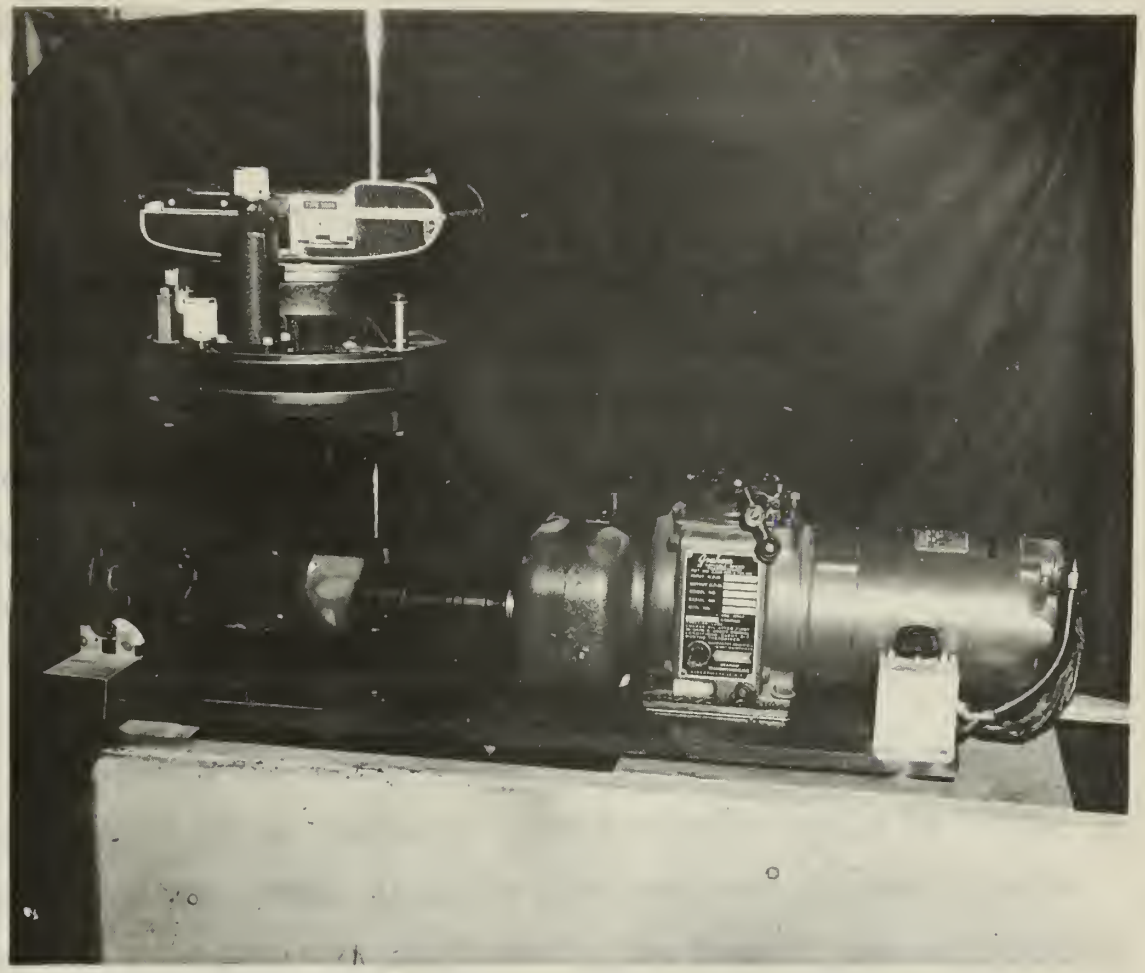


Figure 8 - Rotating mirror and camera assemblies

The rotating mirror assembly includes:

a. Electric motor - Marathon Electric, Mod. VE.

b. Graham variable speed transmission

c. Mirror

The camera assembly includes:

a. Fairchild (manually operated) shutter type K-38

b. Auto Topcor 1:18 lens

c. Polaroid land camera back type 2620

voltage trace. As the photomultiplier tube trace goes from in phase to out of phase and again into phase with the voltage trace, it traverses one wavelength. This can be read directly on a centimeter scale on the photomultiplier tube track.

When the discharge was not stable, rotating mirror photographs were analyzed to determine wavelengths of the moving striations. Each photograph shows calibration marks of a known distance along the tube. Striations could be counted between these marks and wavelength figured directly from this information.

2.7 Frequency Measurements

Frequency was measured in two ways, depending upon the stability of the striations. The frequency could be calculated from data taken directly from the oscilloscope traces when the discharge was stable. In the case of instability, frequency was figured directly from an analysis of the rotating mirror photographs using the relationship $v=\lambda\nu$, where v is the velocity, λ is the wavelength, and ν is the frequency.

2.8 Velocity Measurements

For a stable discharge, the velocity was determined by using the relationship mentioned in Paragraph 2.7. For the unstable discharge, the velocity was calculated from rotating mirror photographs using the following relations:

$$(1) \qquad \Delta x = v_s t$$

(2) $\Delta y = 2R\omega t$

(3) $\frac{\Delta y}{\Delta x} = \tan \theta = \frac{2R\omega}{v_s}$

(4) $v_s = 2R\omega \cot \theta$

R = tube to mirror distance (55 cm for all photographs analyzed)

$= 2\pi$ (revolutions per second) $= \frac{2\pi N}{60}$ sec

Striation velocity = 11.5 N cot θ $\frac{cm}{sec}$

Values of velocity determined by different methods compared favorably. The percentage difference was normally less than ten percent.

3.0 Observations

3.1 Background

This investigation was undertaken to gain more knowledge of the low current, low pressure regions of a neon glow discharge. Reports have been made of the absence of striations above a critical current with values in the hundreds of milliamperes /25/. Some information has also been reported of a striation free region at lower currents. Pekarek reported finding a striation free region as shown in Figure 9, reproduced from his paper /14/. However, he states he was unable to go below currents of 1.2 ma because of the unstable operation of the discharge and because of the interruption by relaxation oscillations. This presented the challenge: to investigate the low current, low pressure region.

The decision was made to begin above the region of no striations and decrease current values until the discharge was lost or instabilities prevented obtaining meaningful data. Two tubes were to be used; one with a diameter corresponding to that used in Pekarek's investigation to obtain some correlation with Figure 9, another of different diameter to note the effect of this change of parameter.

Pressures from 10 mm of mercury down to 50 microns were investigated at currents from 7 ma down to 0.01 ma where a discharge was able to be maintained. Hot and cold cathodes and a Pupp anode were to be used where necessary, although none produced a change of effect in determining limiting

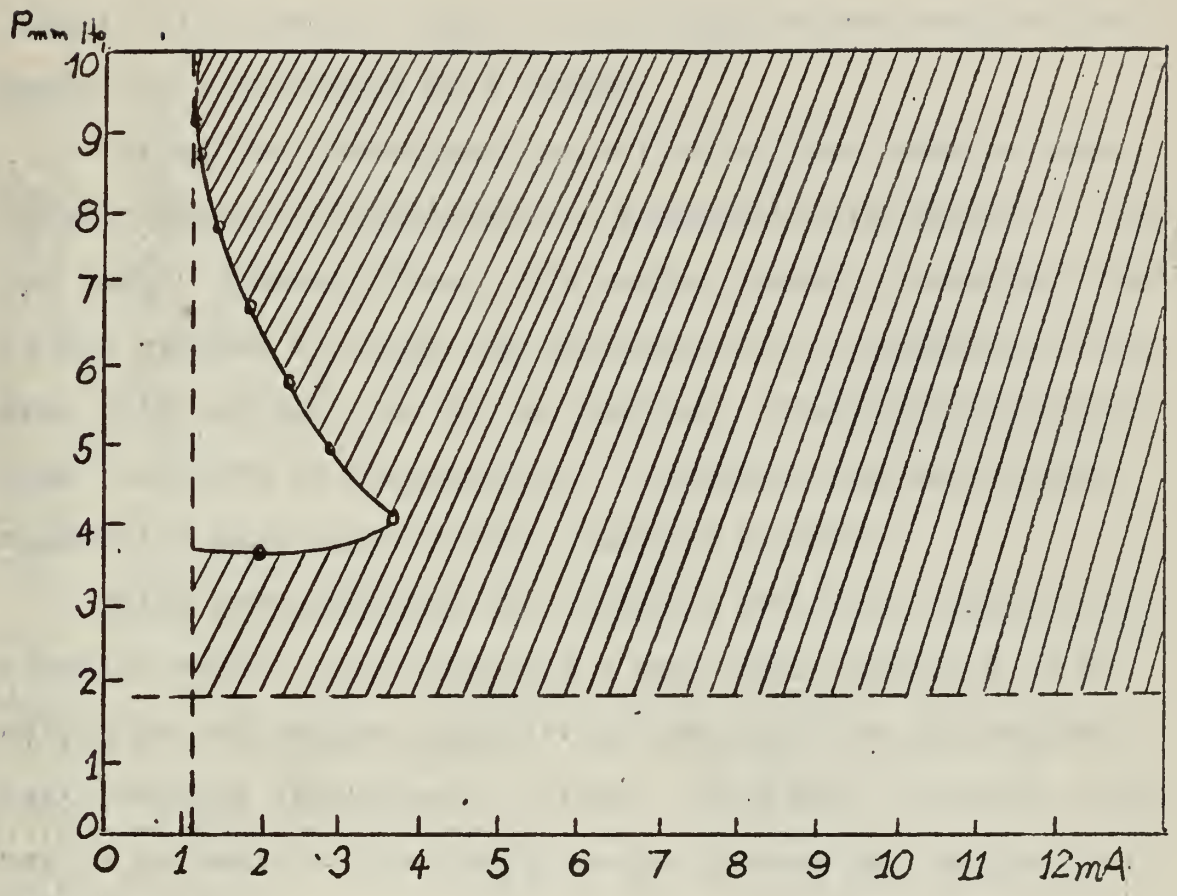
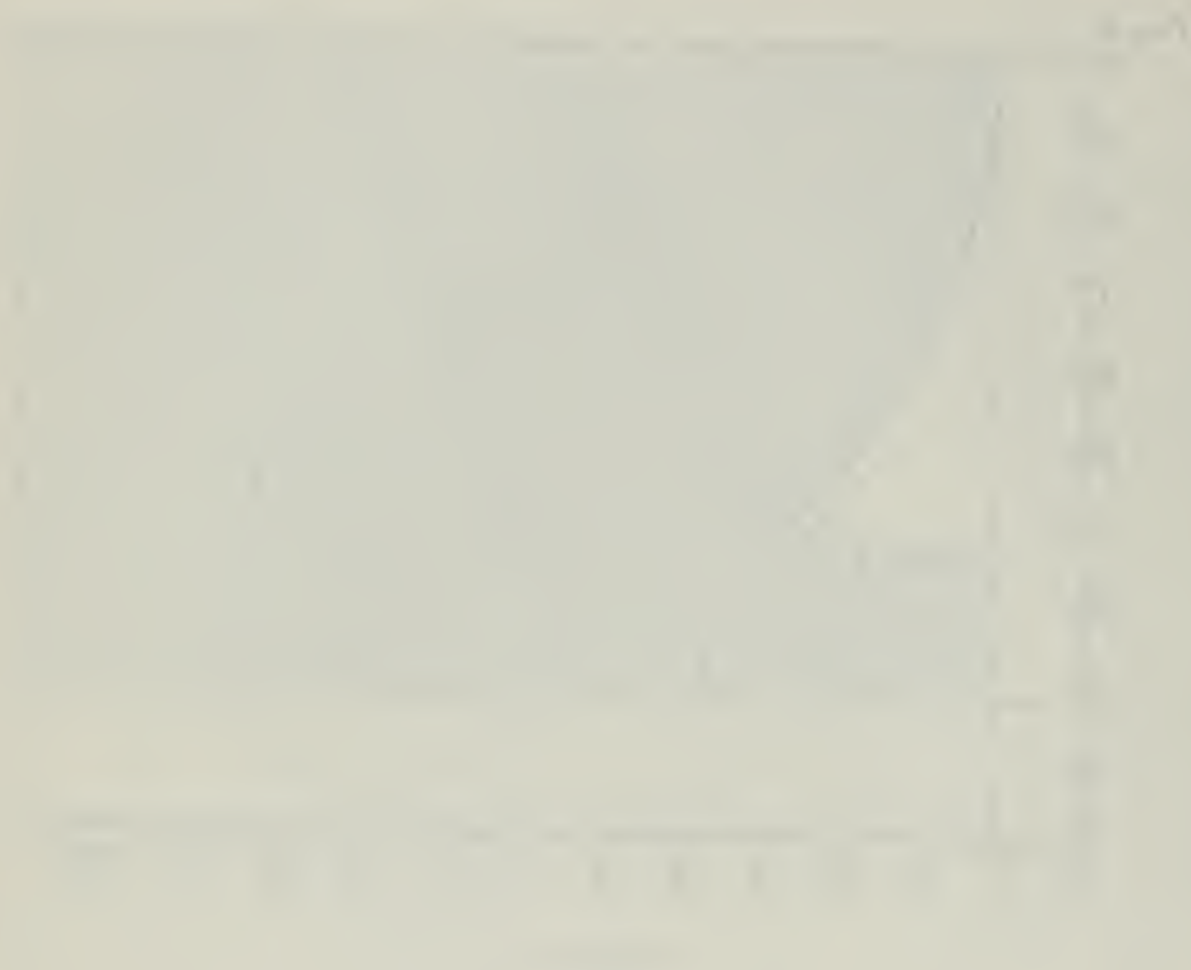


Figure 9

Pekarek's pressure verses current plot showing his region without oscillations in a discharge in neon. Tube diameter = 0.55 cm, length = 60 cm. Lined area is the region of self excited low-frequency oscillations. Data was not obtained below or to the left of dashed lines.



values of the regions of interest. No evidence of striations in rotating mirror observations and no potential or light intensity fluctuations noted in the oscilloscope would be the basis for a striation free region.

During the investigation, striation free regions were found, though not completely in agreement with Figure 9. In the larger diameter tube, this region normally extended down to the current at which the discharge was extinguished; however this was not true in the smaller. New striations were seen to return at much greater frequencies and much higher velocities than those of the original pattern.

While investigating the unstable striation region, the rotating mirror also presented a wave which appeared to be moving in a direction opposite to the positive striations and causing a disturbance in them. This wave, however, could not be detected on the oscilloscope through the photomultiplier tube.

The photographs and graphs in the following section describe the results of this low current, low pressure region investigation.

3.2 Pressure versus Current Plots

Figures 10 and 11 indicate the limits of the striation regions in the areas of current and pressure shown, for two different tube diameters. Although the region boundaries for the two tubes are not similar, the regions do lie in the same areas; e.g. both tubes presented unstable striation

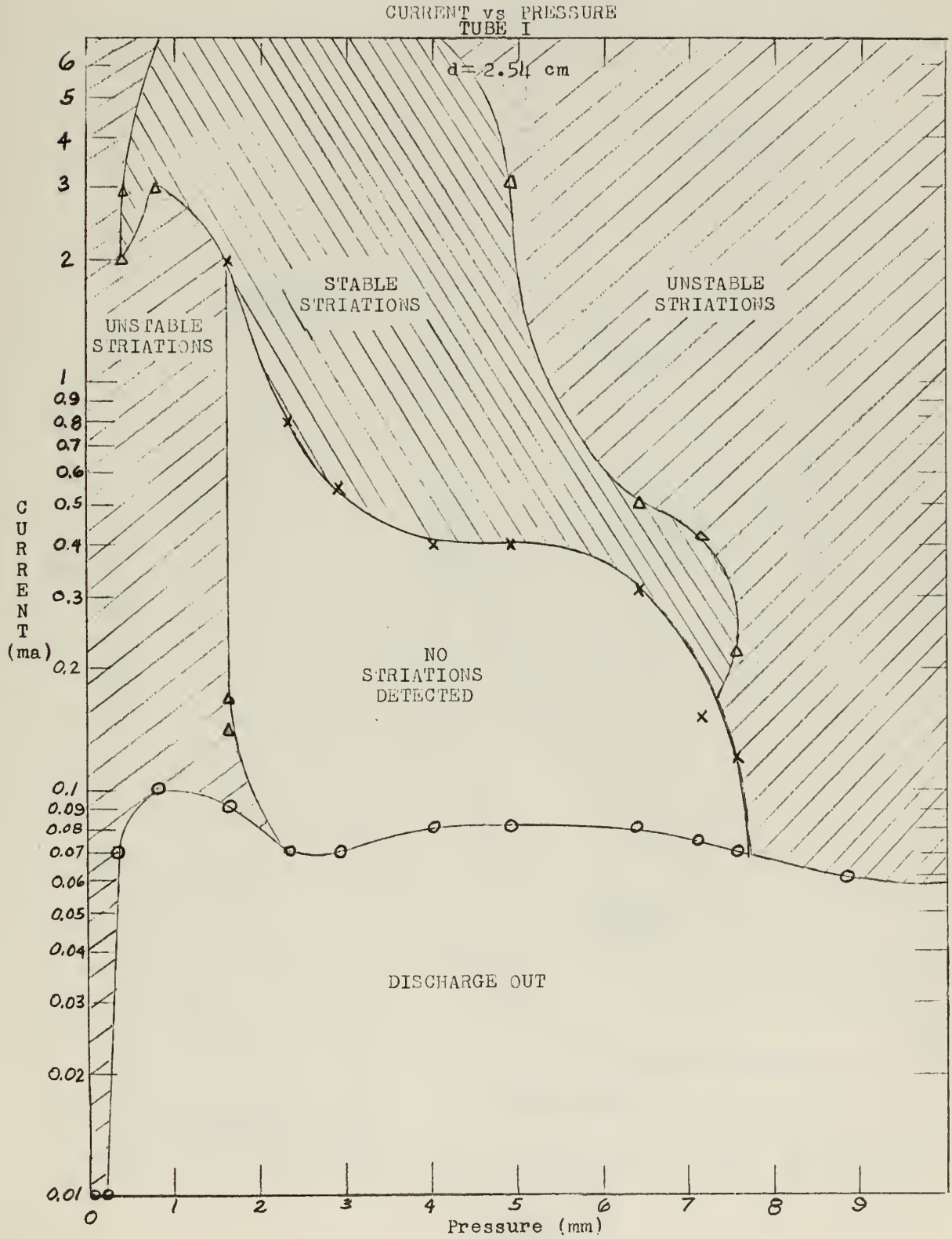

CURRENT vs PRESSURE
TUBE I
d = 2.54 cm
STABLE STRIATIONS
UNSTABLE STRIATIONS
UNSTABLE STRIATIONS
NO STRIATIONS DETECTED
DISCHARGE OUT
CURRENT (ma)
Pressure (mm)
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
2
3
4
5
6
7
8
9

Figure 10

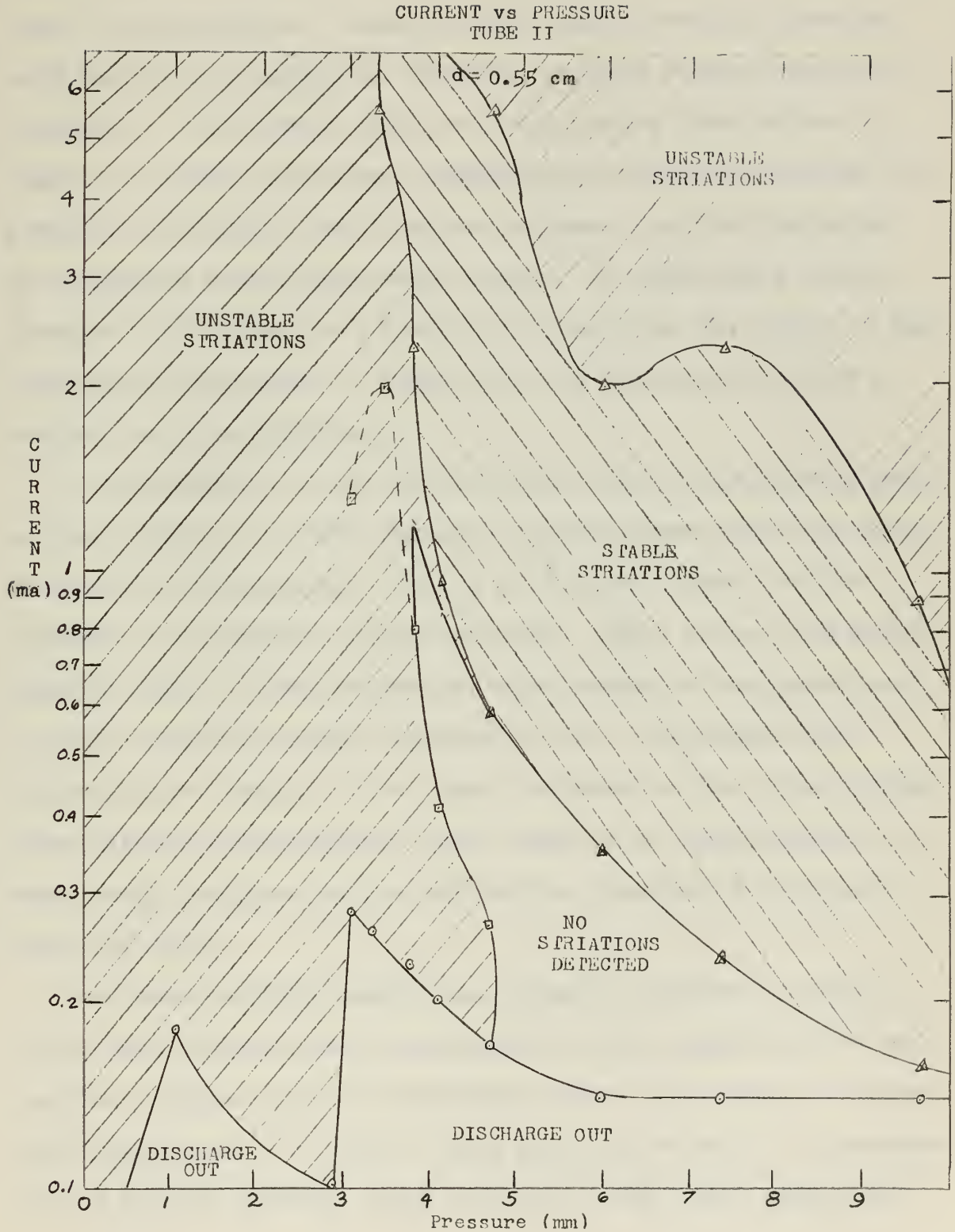

CURRENT vs PRESSURE
TUBE II
d = 0.55 cm
UNSTABLE
STRIATIONS
UNSTABLE
STRIATIONS
STABLE
STRIATIONS
NO
STRIATIONS
DETECTED
DISCHARGE OUT
DISCHARGE
OUT
CURRENT
(ma)
Pressure (mm)
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9

Figure 11

patterns in the higher and lower pressure areas investigated, and, in most cases, stable striations were present prior to their disappearance. Data for the stable-unstable boundary were taken in a manner to show the largest stable region obtainable. The current point was approached from either a higher or lower direction, depending upon which produced the greatest stability, and time was allowed for the discharge to stabilize before data were taken. No hysteresis effect greater than 1% was noted which is less than the error of the measuring instruments. Therefore, any hysteresis effects present was insignificant.

The boundary of the no striation region was established at the current of their complete disappearance from the tube. The actual disappearance of the striations begins at the cathode at a slightly higher current. This value, was never greater than 0.75 ma above the value shown on the graph and in most instances never exceeded 0.2 ma. Although this value appears small, it is large compared to the total range investigated and indicates that there is an appreciable current range required before striations completely disappear from the tube.

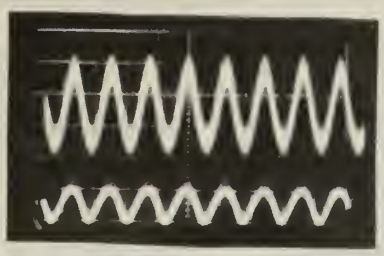
A characteristic which was slightly evident in tube I (2.54 cm), but much more pronounced in the tube II (0.55 cm) was the reappearance of striations after all traces of these had disappeared. In tube I this was only noted at a pressure of 1.6 mm and currents from 0.17 ma to the point where the

discharge was lost. In a narrow band of current (0.17-0.14 ma) these striations were stable. In tube II the striations returned for pressures of 3.8-4.7 mm. These striations were very different, however, from those last seen before disappearance. Although in most cases they were extremely unstable and data was difficult to obtain, it was evident that their velocity and frequency had increased considerably. In the few measurable cases the increase was by a factor of ten. These fast striations remained visible until the discharge was lost.

Another interesting phenomenon occurred in tube II in the pressure region of 3.1-3.7 mm where striations described above began at the same current or higher than that at which the slower striations disappeared. This is indicated in Figure 11 by the dashed line. In the area below this line the low and high velocity striations were visible together for a time before the slow striations disappeared as the current was decreased. Therefore, there was never a striation free region. This may be the same phenomenon reported by Pekarek /8/, who noted a second set of striations, travelling much faster than normal, at rather low currents. His reported velocities are somewhat higher than our observations, however, and he makes no statement concerning an initial loss of striations before the appearance of this fast set.

3.3 Rotating Mirror and Oscilloscope Photographs for Neon

Figure 12 is a pair of photographs showing a typical



Upper: Light intensity waveform 45cm from cathode. Time base, 0.5 msec/cm. Vertical defl. 10 mv/cm

Lower: Tube voltage oscillation. Vertical deflection, 1 v/cm

(a)

(b)

Typical stable striation pattern, Tube I. Pressure, 4.9 mm Hg. Current, 3.1 ma. Wavelength, 5.65 cm. Frequency, 1540 cps. (a) Oscilloscope trace photograph. (b) Rotating mirror photograph. Cathode to left. Tube diameter, 2.54 cm.

Figure 12

stable striation pattern in tube I. Figure 12b is the rotating mirror photograph of the tube and photograph a is the corresponding oscilloscope photograph taken at a position 45 cm from the cathode. The photos were taken at a current of 3.1 ma and a pressure of 4.9 mm.

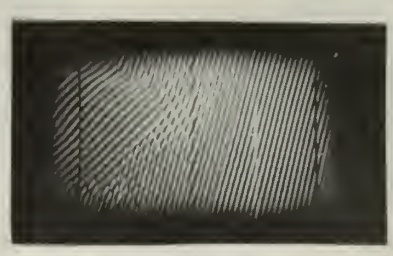
Figures 13, 14, 15, and 16 show a sequence of rotating mirror photographs at constant current and varying pressures for tube II. These move from the unstable region, through the stable region, and into the unstable region again. Unfortunately, a sequence could not be obtained at lower currents due to the low light intensity. Although 3000 speed film was used, significant detail is lost in reproduction and the slightest movement of the striation pattern with a time exposure again destroys the significant details. In all rotating mirror photographs time increases upward. Therefore a horizontal line across the photo would indicate the condition in the tube at a particular time. In the rotating-mirror photographs of the small tube, the apparent disturbance in the center of the tube is due to the probe being located at this point, although withdrawn into a side tube.

Note the extremely complicated pattern at higher and lower pressures. Also quite evident at pressures of 3.4 and 9.7 mm, Figure 16, are wave-like disturbances moving from cathode to anode which appear to be influencing the positive striations moving from anode to cathode, so as to increase the velocity of these striations at each point of interaction.

P = 9.7 mm

P = 7.4 mm

P = 6.0 mm



P = 4.7 mm

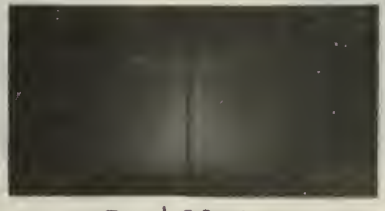
Current, 7.0 ma. Tube diameter, 0.55 cm. Cathode to right.

Figure 13

P = 3.4 mm

P = 2.9 mm

P = 1.1 mm



P = 400 μ

Current, 7.0 ma. Tube diameter, 0.55 cm. Cathode to right.

Figure 14

P = 9.7 mm

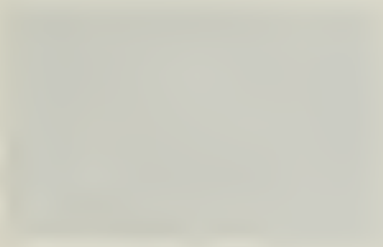
P = 7.4 mm

P = 6.0 mm

P 4.1 mm

Current, 3.0 ma. Tube diameter, 0.55 cm. Cathode to right.

Figure 15



P = 3.8 mm

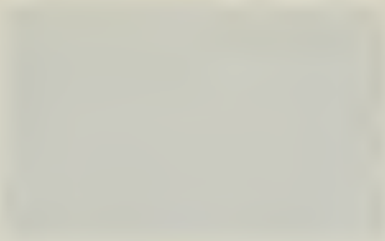
P = 3.4 mm

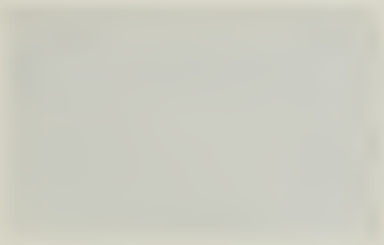
P = 2.9 mm

P = 1.1 mm

Current, 3.0 ma. Tube diameter, 0.55 cm. Cathode to right.

Figure 16

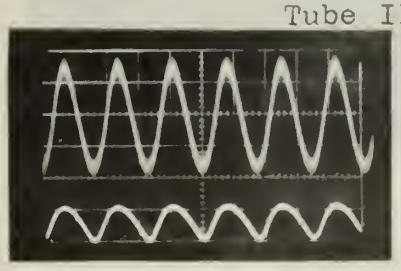




This wave effect appears similar to that found in argon by Pelton and North /29/, but the effect on the positive striations in our case is opposite. If this disturbance can be considered a wave, its velocity may be determined in the same manner as the positive striations. This indicates velocities from 230-1000 meters/second in all photos interpreted. Although velocities vary in any one photo, no correlation can be noted in these wave velocities with distance from cathode, and no effect is noted in the wave pattern due to the interaction with the striations. No evidence of these waves was seen in the oscilloscope. Figure 17 is a sequence of oscilloscope photographs for tube II at a pressure of 4.1 mm Hg and a distance of 54 cm from the cathode. The photographs a through d show, respectively, stable striations, unstable striations, no striations, and return of high frequency striations. The current at which each photo was taken is indicated on the figure. Note that as current is reduced, the striations phenomena in the tube pass through the four striation regions, as shown in Figure 11.

Figure 18 is a set of three photographs showing conditions in tube I at a current of 6.6 ma and a pressure of 750 microns Hg. Figure 18a is a rotating mirror photograph indicating the loss of striations at the cathode. Figures 18b and c are oscilloscope photos showing striation and voltage patterns 53 cm and 3 cm from the cathode respectively. Note that although the striations have almost disappeared at the

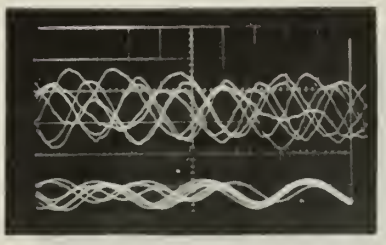
Tube II Diameter 0.55 cm.



Upper: Light intensity waveform. Time base, 0.1 msec/cm. Vertical deflection, 5 mv/cm.

Lower: Tube voltage oscillation. Vertical deflection, 0.5 v/cm

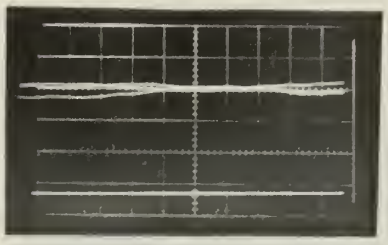
(a) Current 3 ma



Upper: Light intensity waveform for six single sweeps. Time base, 0.1 msec/cm. Vertical deflection, 5 mv/cm.

Lower: Tube voltage oscillation. Vertical deflection, 0.5 v/cm.

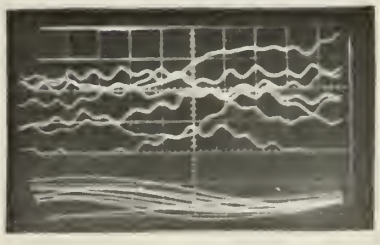
(b) Current 0.94 ma



Upper: Light intensity waveform for four single sweeps. Time base, 20 sec/cm. Vertical deflection, 5 mv/cm.

Lower: Tube voltage oscillation. Vertical deflection, 0.5 v/cm.

(c) Current 0.50 ma



Upper: Light intensity waveform for seven single sweeps. Time base, 20 sec/cm. Vertical deflection, 1 mv/cm.

Lower: Tube voltage oscillation. Vertical deflection, 0.5 v/cm.

(d) Current 0.41 ma

Pressure 4.1 mm Hg. Distance from cathode 54 cm. Note that photos (b)-(d) are single sweep oscilloscope traces.

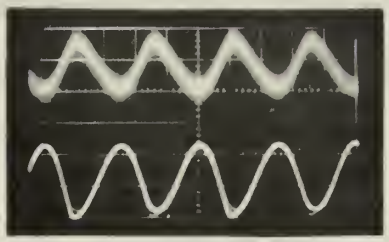
Figure 17

(a)

Tube T, Diameter, 2.54 cm.

Rotating Mirror Photograph

Cathode to left.

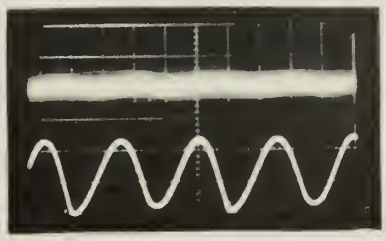


(b)

Upper: Light intensity waveform.
Time base, 20 sec/cm.
Vertical deflection, 5 mv/cm.

Lower: Tube voltage oscillation.
Vertical deflection, 0.1 v/cm.

54 cm from cathode.



(c)

Upper: Light intensity waveform.
Time base, 20 sec/cm.
Vertical deflection, 5 mv/cm.

Lower: Tube voltage oscillation.
Vertical deflection, 0.1 v/cm.

3 cm from cathode.

Pressure = 750 μ Hg

Current = 6.6 ma

Wavelength 4.65 cm. Frequency 19,200 cps

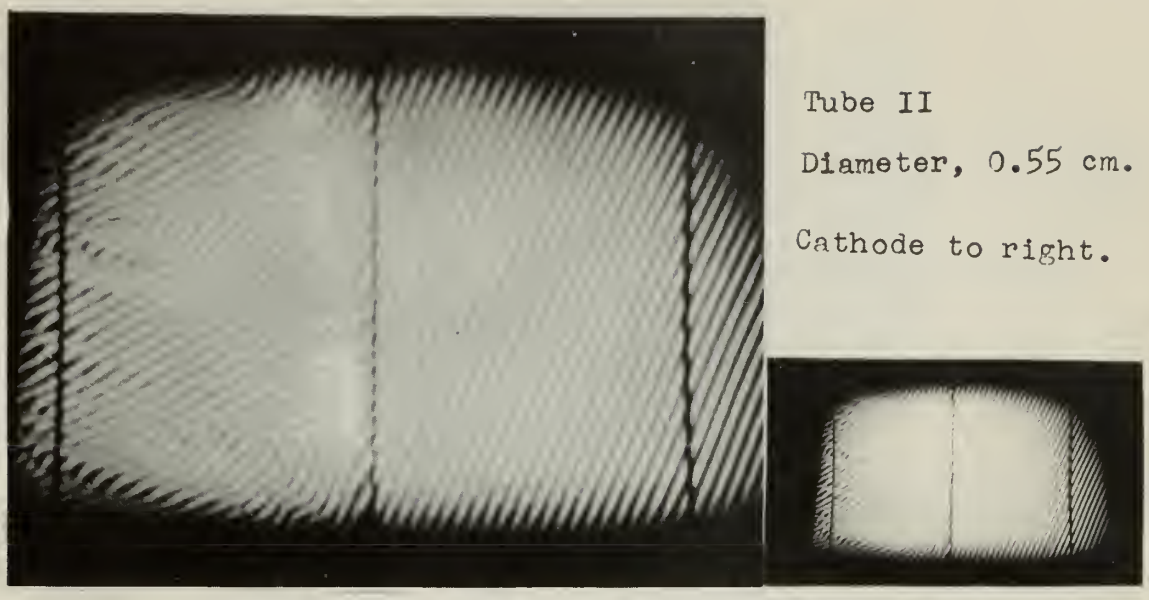
Figure 18

cathode end, the voltage wave form has remained unchanged.

Figure 19 is a series of photographs taken at a current of 7.0 ma and a pressure of 4.7 mm Hg. in tube II. The rotating mirror photo indicates the complexity of the striation pattern in the discharge at these parameters. Figure 19b is an oscilloscope photo representative of any photomultiplier tube position along the tube. Note the complete lack of usable information displayed. Figure 19c is a single sweep oscilloscope photo taken 54 cm from the cathode indicating the instability at this region (left of center, toward anode, in photo a). Figure 19d is a single sweep photo taken 16 cm from the cathode, indicating a fairly stable pattern (right portion of photo a) in agreement with the rotating mirror photograph for this position. It can be seen that although the normal oscilloscope photo might appear to be hopelessly complex, single sweep photos present useful information.

Figure 20 presents two photographs of a typical unstable condition in tube I. Figure 20a was taken at a current of 2.3 ma and a pressure of 10.1 mm Hg. Figure 20b was taken at a current of 6.5 ma and pressure of 7.5 mm Hg. Note the extreme changes in the slope of the striations indicating a rapid change to a much higher velocity for a short period and a drop to a lower velocity again. These changes occur so as to indicate a wave moving in the opposite direction.

Figure 21 is a pair of oscilloscope photographs indicating a double striation phenomenon in tube II. Figure 21a

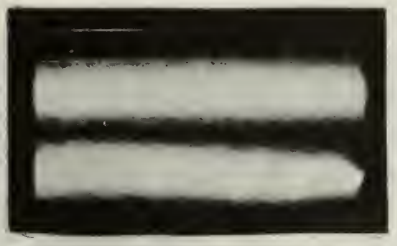


Tube II

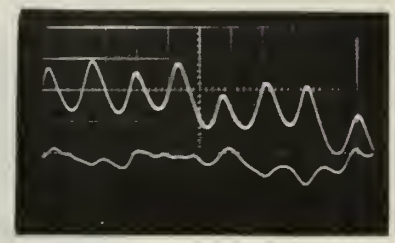
Diameter, 0.55 cm.

Cathode to right.

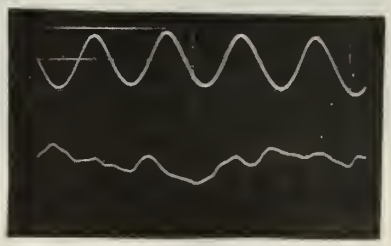
(a)
Rotating Mirror Photograph



(b)



(c)
Single sweep
54 cm from cathode



(d)
Single sweep
16 cm from cathode

Pressure = 4.7 mm. Current = 7.0 ma. Upper traces are light intensity waveforms. Time base, 50 sec/cm. Vertical deflection, 2 mv/cm. Lower trace is tube voltage oscillation.

Figure 19

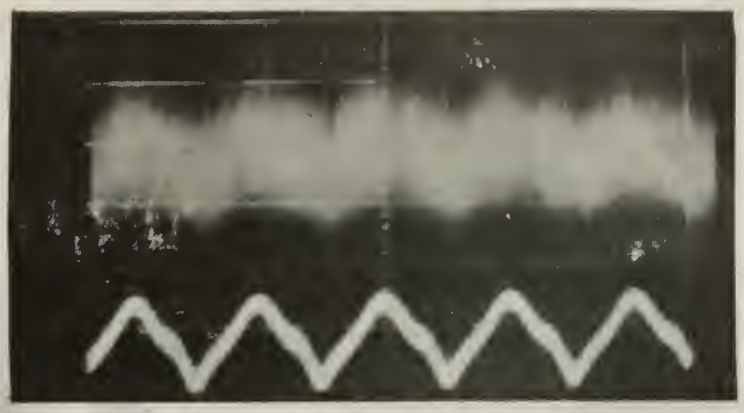
Pressure, 10.1 mm
Current, 2.3 ma
Anode to right.

(a)

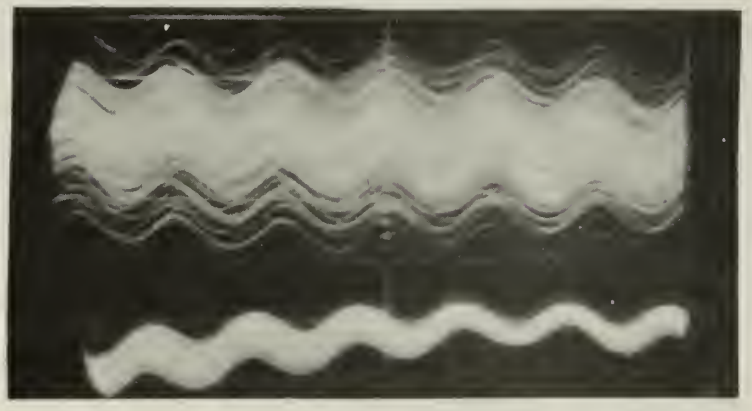
Pressure, 7.5 mm
Current, 6.5 ma
Anode to left.

(c)

Tube I
Diameter, 2.5 cm
Pouring Lamor precession



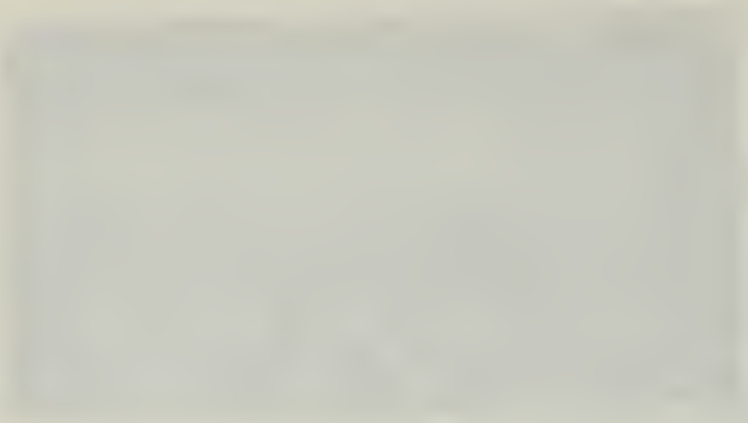
(a)



(b)

Tube II. Pressure, 3.4 mm. Current, 1.0 ma. Upper trace: light intensity waveform. (a) Time base, 0.2 msec/cm. Vertical deflection, 2 mv/cm. (b) Time base, 10 sec/cm. Vertical deflection, 2 mv/cm. Lower trace: voltage oscillation waveform. Vertical deflection, (a) 0.1 v/cm (b) 0.05 v/cm. Wavelength, (a) 2.8 cm, (b) 0.9 cm. Frequency, (a) 2275 cps, (b) 55,600 cps. Distance from cathode, 58 cm for both photographs.

Figure 21



shows the two patterns, one riding on the other, taken at a time base of 0.2 millisecond/cm. The velocity of the slow striation is 63.6 meters/second, the frequency, 2275 cps. Figure 21b is a greatly expanded photo of the faster striation moving at a velocity of 500 meters/second and a frequency of 55,600 cps taken at a time base of 10 micro-seconds/cm. Both striation patterns are moving toward the cathode. Photographs were taken at a current of 1 ma and 3.4 mm Hg.

3.4 Current versus Various Parameters

Graphs are discussed in terms of decreasing currents and pressures; the order in which data were normally taken. Note that in all graphs showing the parameters as a function of current, the current is presented on a logrithmic scale. This is done to allow graphical presentation of the current range investigated on a single graph.

Figures 22 and 23 present the voltage across the tube as a function of current for both tubes. Resulting curves are similar to reports published by other investigators, although working in different gases and at higher to much higher currents. These curves indicate an increasing voltage with decreasing current. At very low current values the voltage increases considerably for a small decrease in current, especially in tube II. An increase of over 100 volts may accompany a decrease in current of 0.1 ma. Although in tube I this relationship appears independent of pressure, tube II

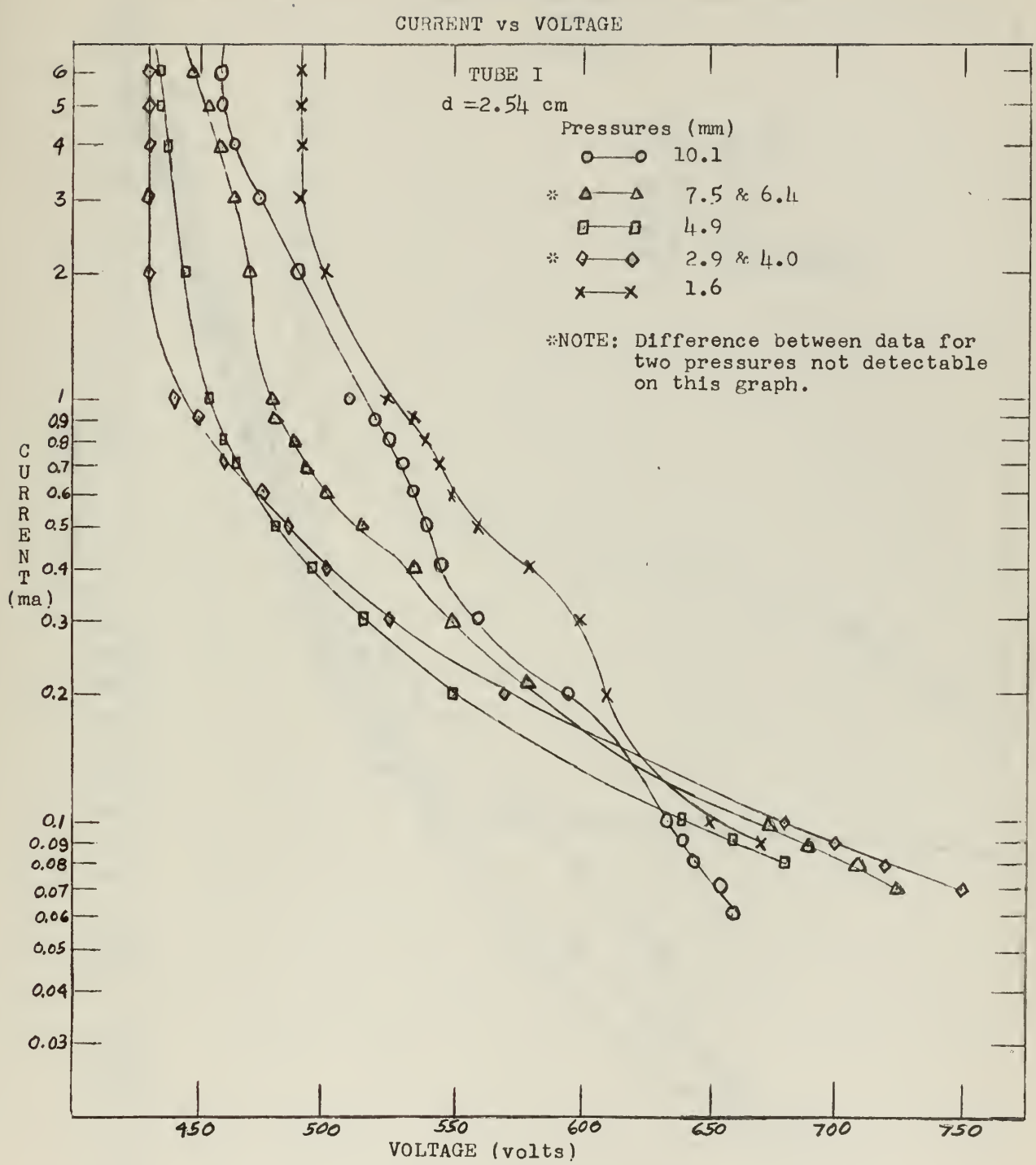

CURRENT vs VOLTAGE
TUBE I
d =2.54 cm
Pressures (mm)
10.1
7.5 & 6.4
4.9
2.9 & 4.0
1.6
*NOTE: Difference between data for two pressures not detectable on this graph.
CURRENT (ma)
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
450
500
550
600
650
700
750
VOLTAGE (volts)

Figure 22

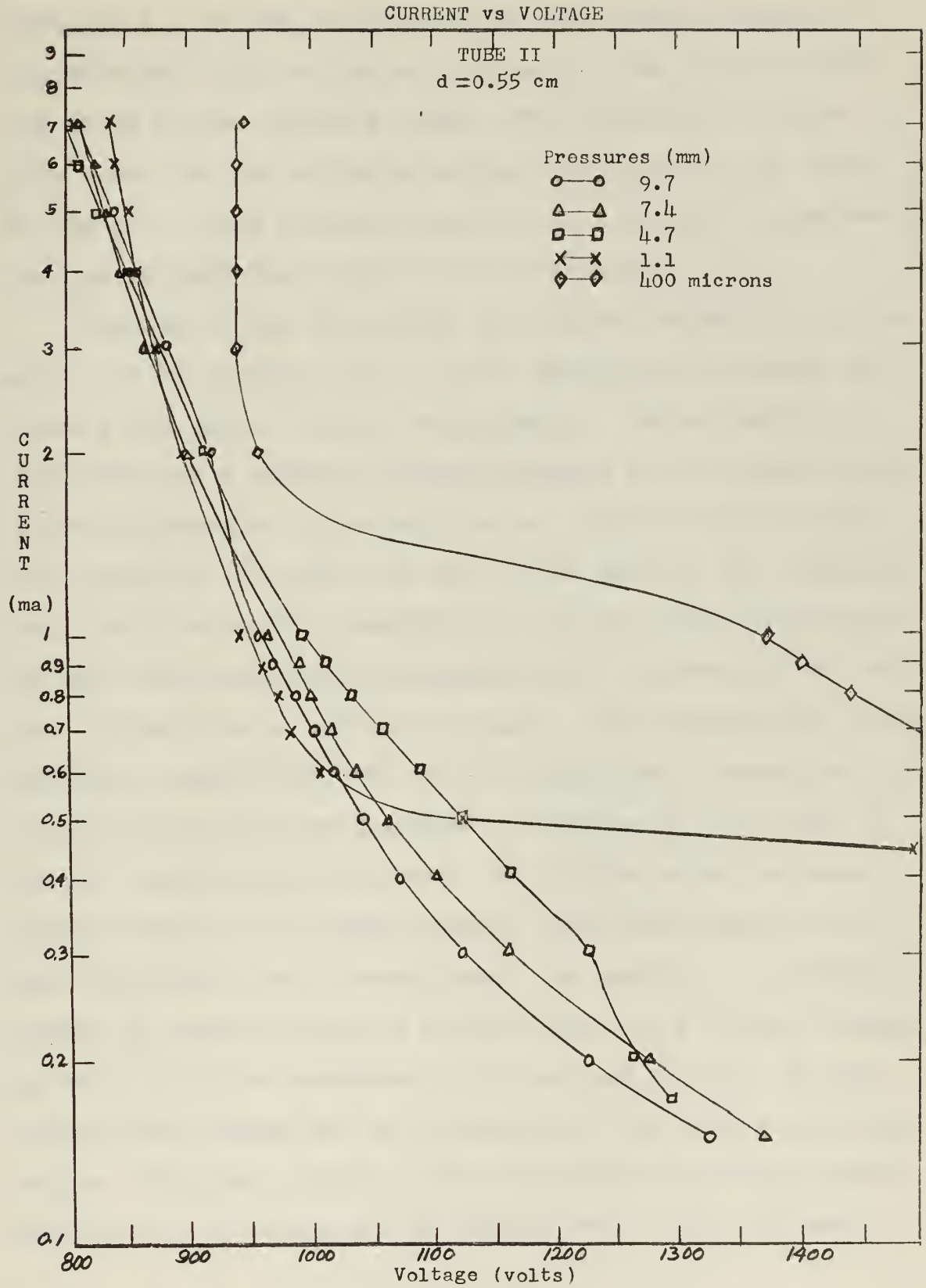

CURRENT vs VOLTAGE
TUBE II
d = 0.55 cm
Pressures (mm)
9.7
7.4
4.7
1.1
400 microns
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
800
900
1000
1100
1200
1300
1400
Voltage (volts)

Figure 23

data indicate a much greater increase for the two lower pressures of 1.1 mm and 400 microns Hg. Not shown because of the extremely high voltages involved are the results from the lower micron pressure range. The curves are similar in this area, but the voltages extend from 5450 to 7500 volts. No change in this voltage-current relationship is noted while passing through the region of no striations.

Figures 24 and 25 present the current velocity relationship. It is evident that velocity decreases as current but there is no simple linear relationship. The velocity of striations at a constant current appears to decrease with decreasing pressure, but exceptions are shown in both tubes. Unfortunately, no plots are able to be made of the outstanding exception to this observation; the very high velocities of the striations which reappeared after decreasing the current through the no striation region. The instability of the striation pattern allowed only an approximate determination of velocity at any one pressure. This was of the order of several hundred meters/second. It is also noted in these graphs that in the larger diameter tube were found the largest velocities and in most cases, the smallest. An abrupt change in velocity appears in this tube for a current change of only 1.0 ma at pressures of 4.0 mm and 2.9 mm. In both cases these points are in the center of the stable striation region. This may indicate that although the photomultiplier tube and the rotating mirror present very stable patterns,

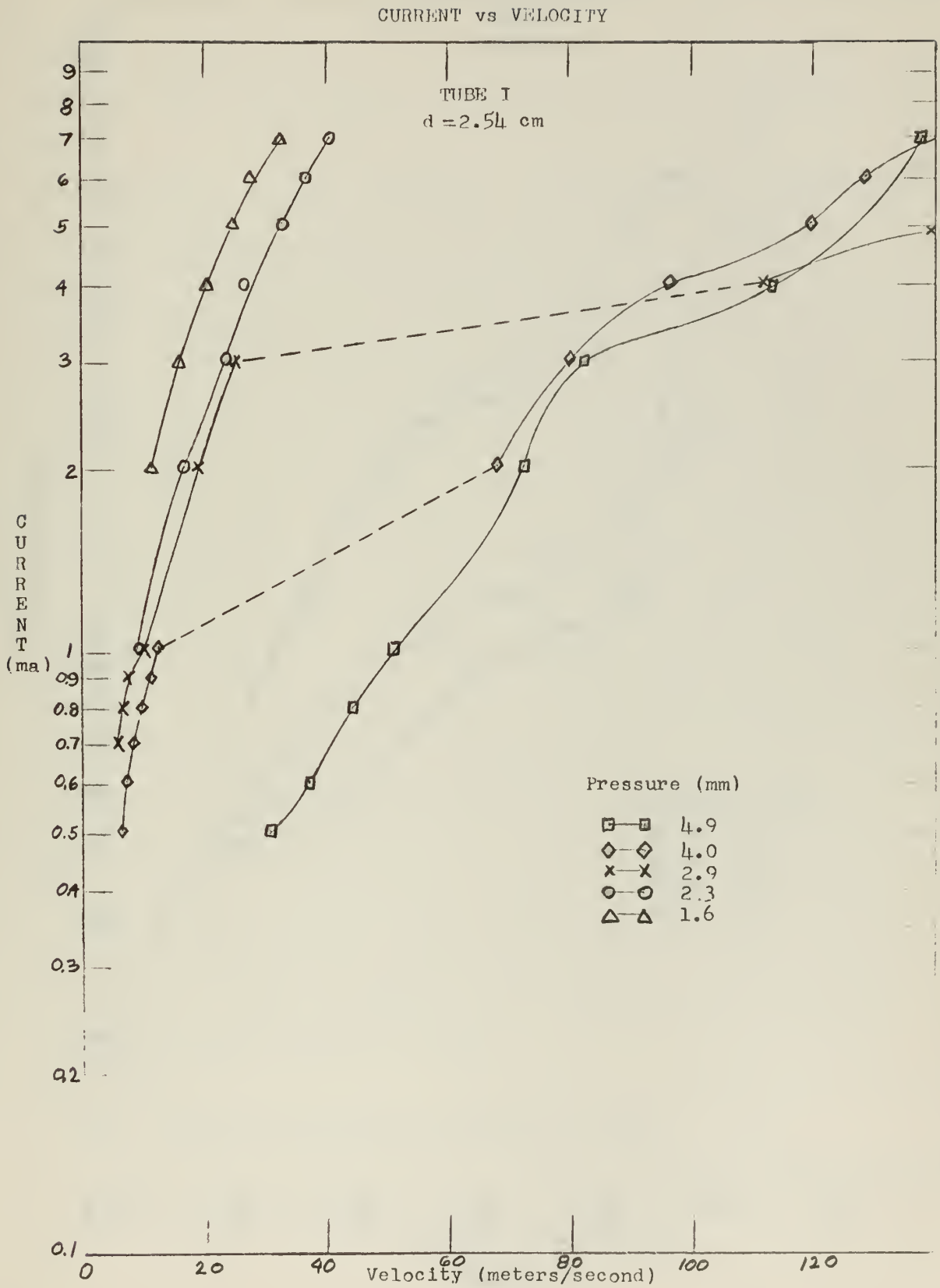

CURRENT vs VELOCITY
TUBE I
d = 2.54 cm
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Pressure (mm)
4.9
4.0
2.9
2.3
1.6
0
20
40
60
80
100
120
Velocity (meters/second)

Figure 24

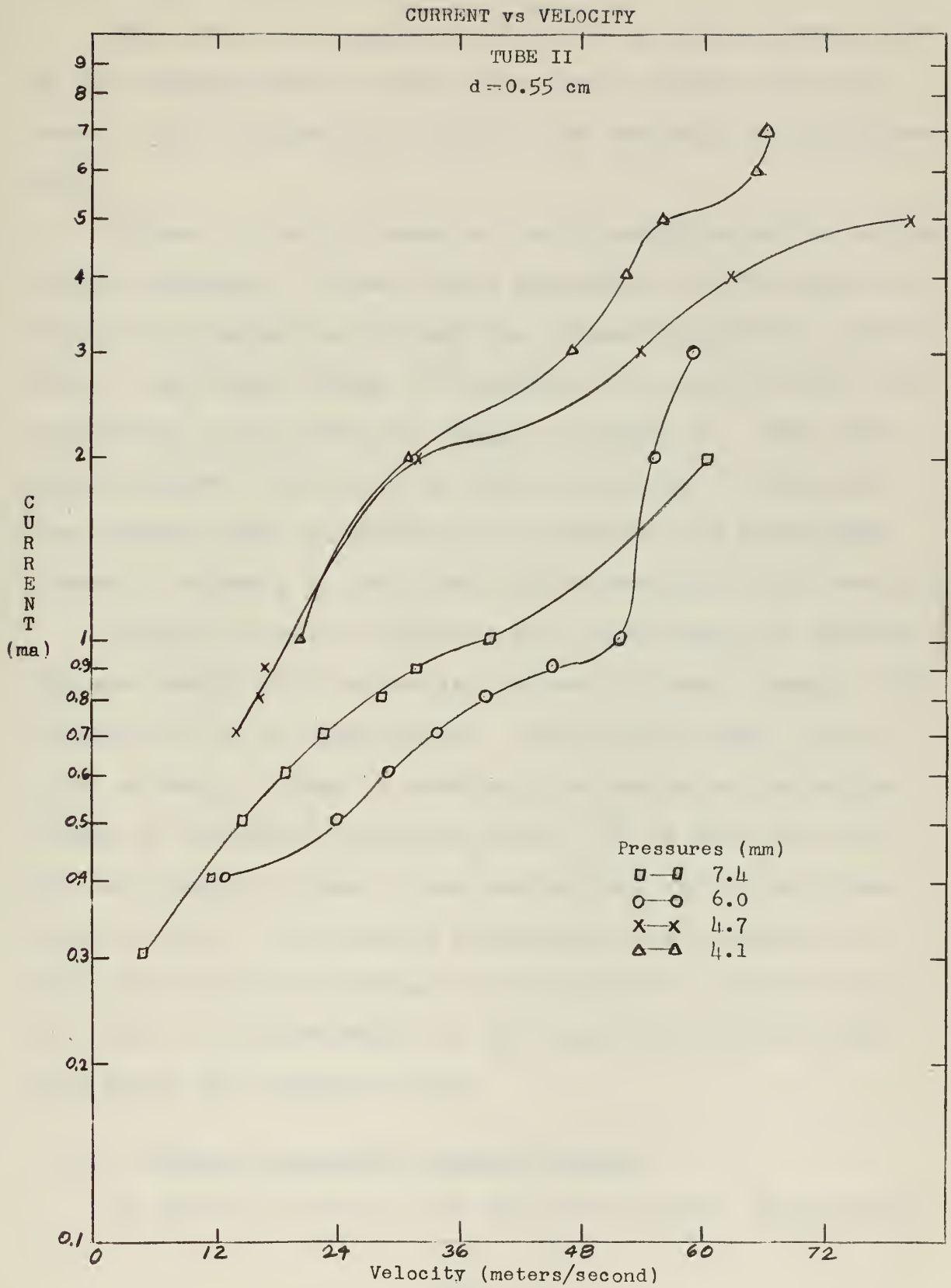

CURRENT vs VELOCITY
TUBE II
d = 0.55 cm
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
24
36
48
60
72
Velocity (meters/second)
Pressures (mm)
7.4
6.0
4.7
4.1

Figure 25

abrupt discontinuities do occur.

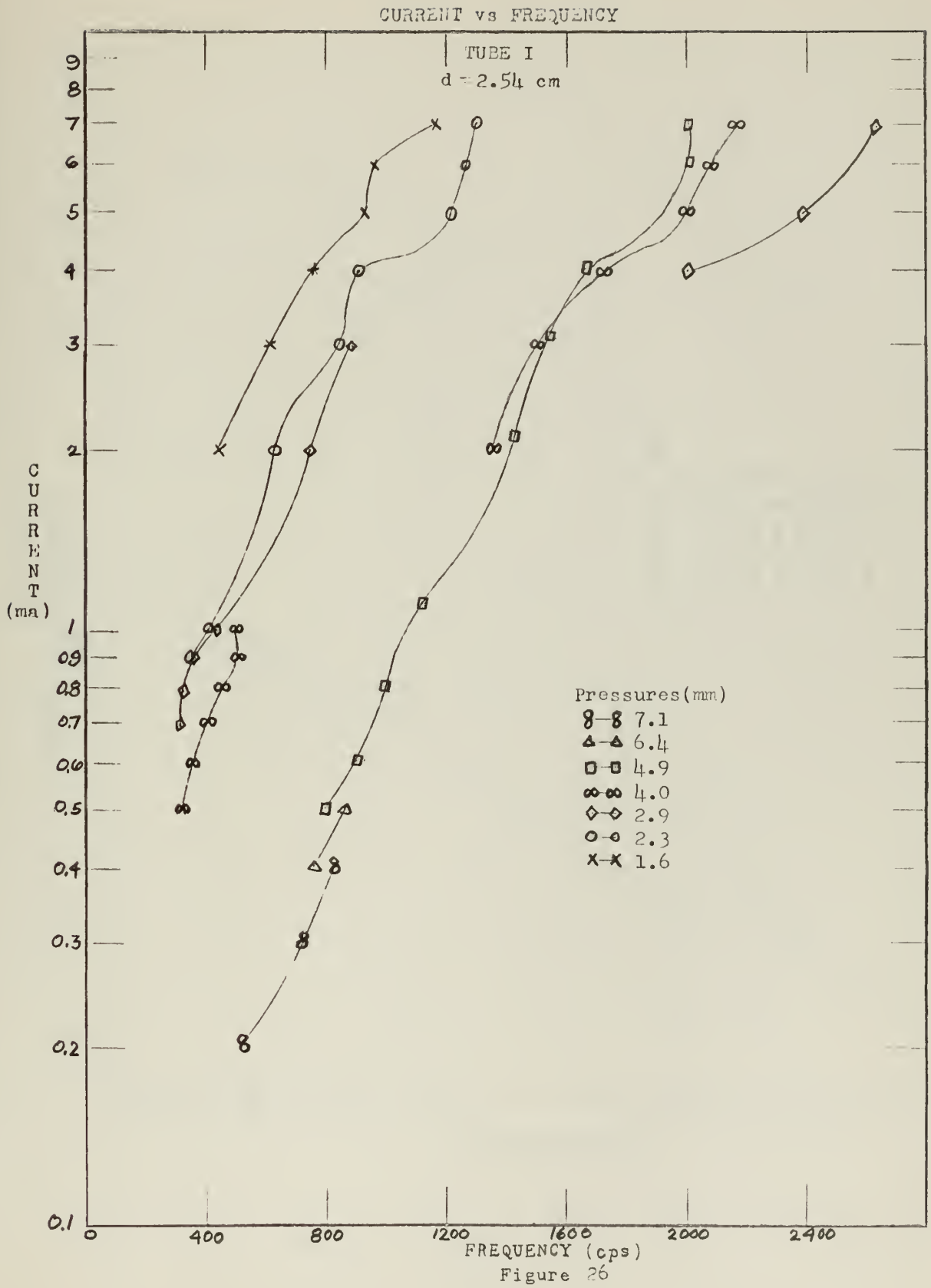
The curves are normally terminated at their lower points by the disappearance of the striations although in a few cases, this termination is due to the unstable striation pattern.

Figures 26 and 27 show the complicated pattern of current versus frequency. These curves are similar to the current-velocity presentation through the frequency-velocity relationship. The abrupt change in frequency is noted in tube I corresponding to the velocity change in Figure 24. Note the high frequency striations on the log-log plot of tube II. Two patterns show an increase in velocity with decreasing current, contrary to the normal relationships in the two tubes.

Figures 28 and 29 indicate the relationship of decreasing wavelength with decreasing current although, again, this relation is by no means simple. Note in the tube I plot that an abrupt change in wavelength accompanied the sudden change in frequency described above. It is also seen that the wavelength in tube II was smaller and varied much less than in tube I. This small wavelength never decreased to less than the tube diameter and although this was not true for tube I, the wavelength in the larger tube did not dip much below the diameter value.

3.5 Various Parameters versus Pressure

In Figures 30 and 31 are seen the distinct similarities


CURRENT vs FREQUENCY
TUBE I
d = 2.54 cm
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Pressures(mm)
7.1
6.4
4.9
4.0
2.9
2.3
1.6
0
400
800
1200
1600
2000
2400
FREQUENCY (cps)
Figure 26

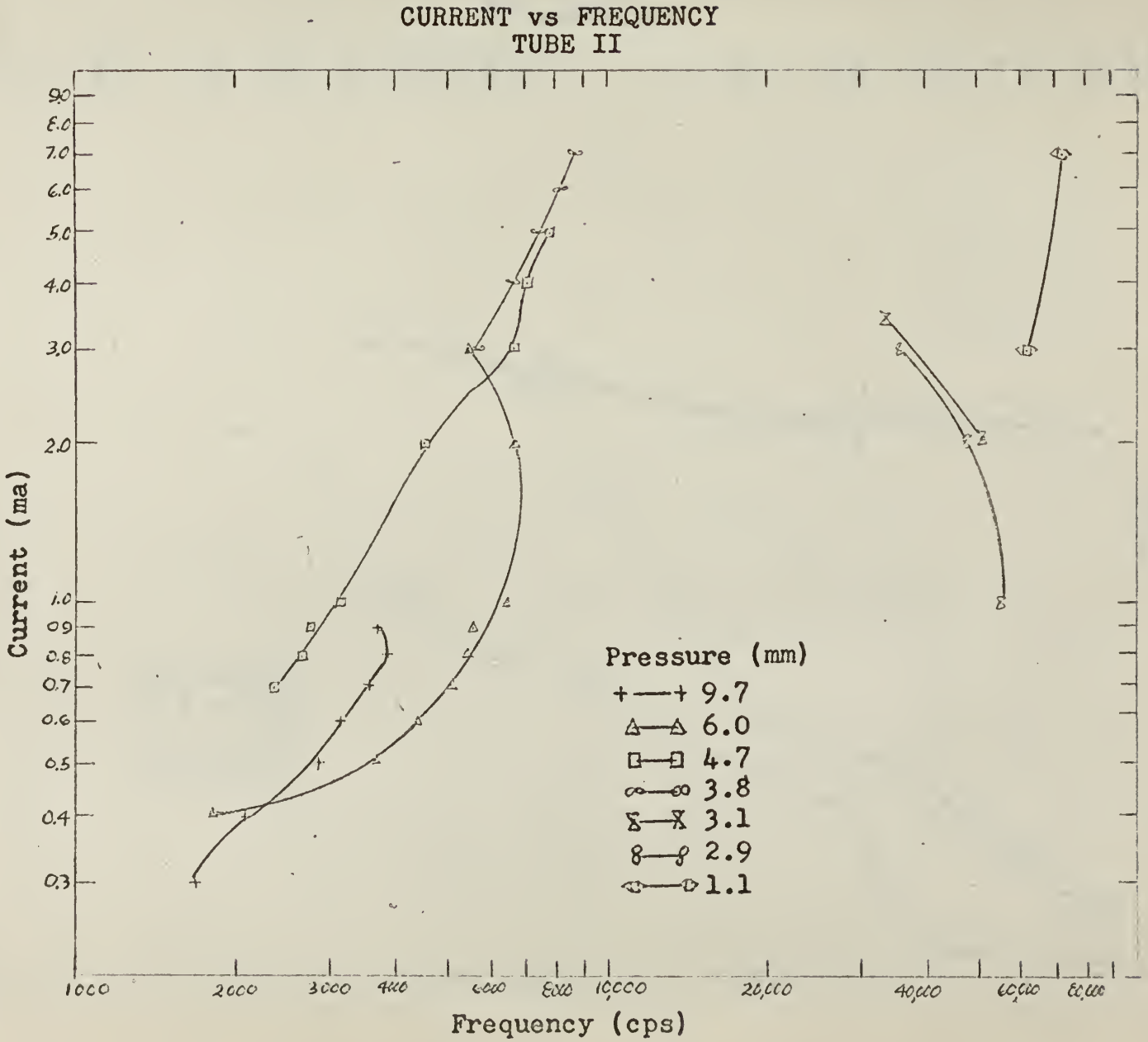

CURRENT vs FREQUENCY
TUBE II
Current (ma)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1000
2000
3000
4000
6000
8000
10,000
20,000
40,000
60,000
80,000
Frequency (cps)
Pressure (mm)
9.7
6.0
4.7
3.8
3.1
2.9
1.1

Figure 27

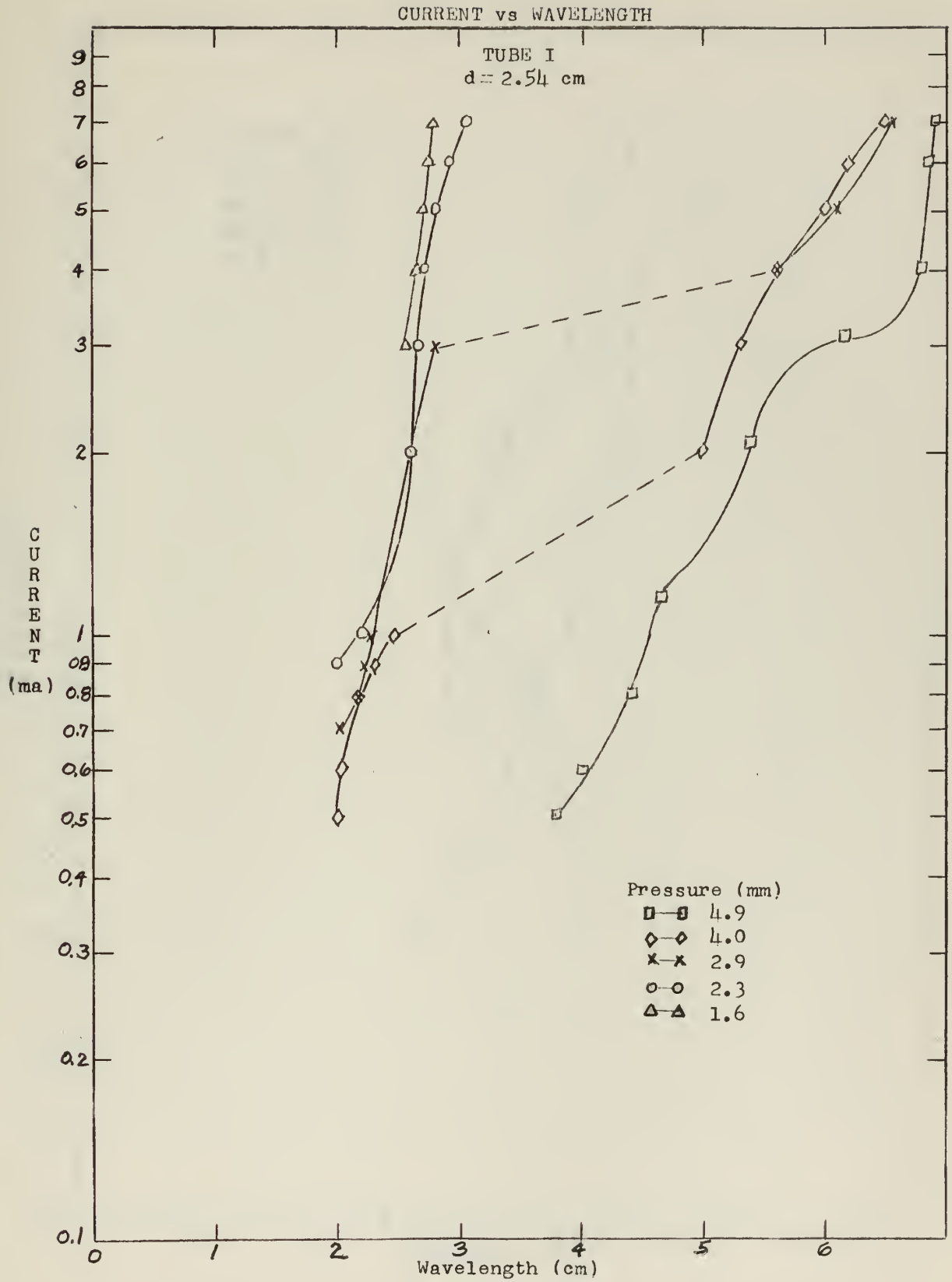

CURRENT vs WAVELENGTH
TUBE I
d = 2.54 cm
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
Wavelength (cm)
Pressure (mm)
4.9
4.0
2.9
2.3
1.6

Figure 28

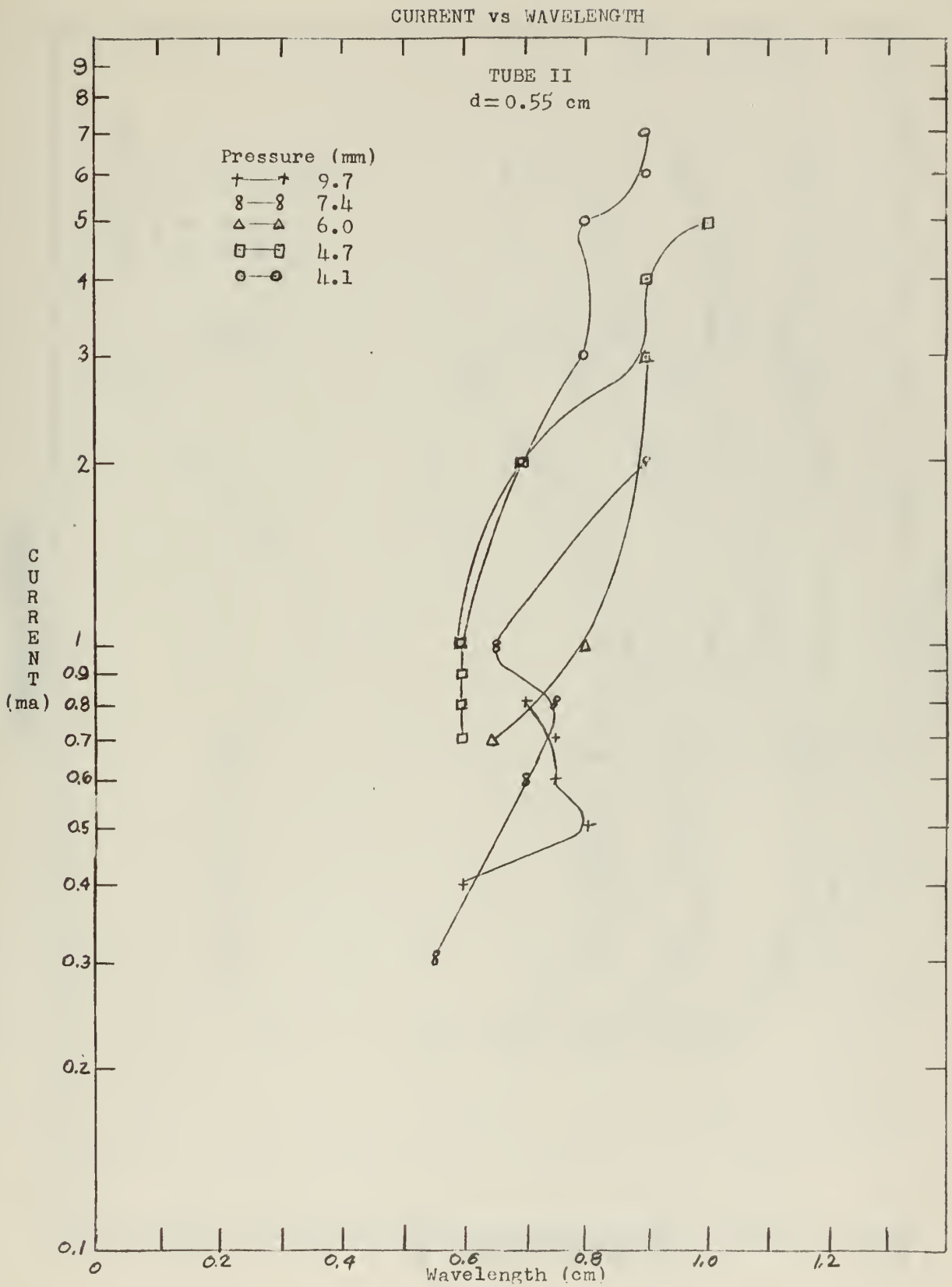

CURRENT vs WAVELENGTH
TUBE II
d = 0.55 cm
Pressure (mm)
9.7
7.4
6.0
4.7
4.1
CURRENT (ma)
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1.0
1.2
Wavelength (cm)

Figure 29

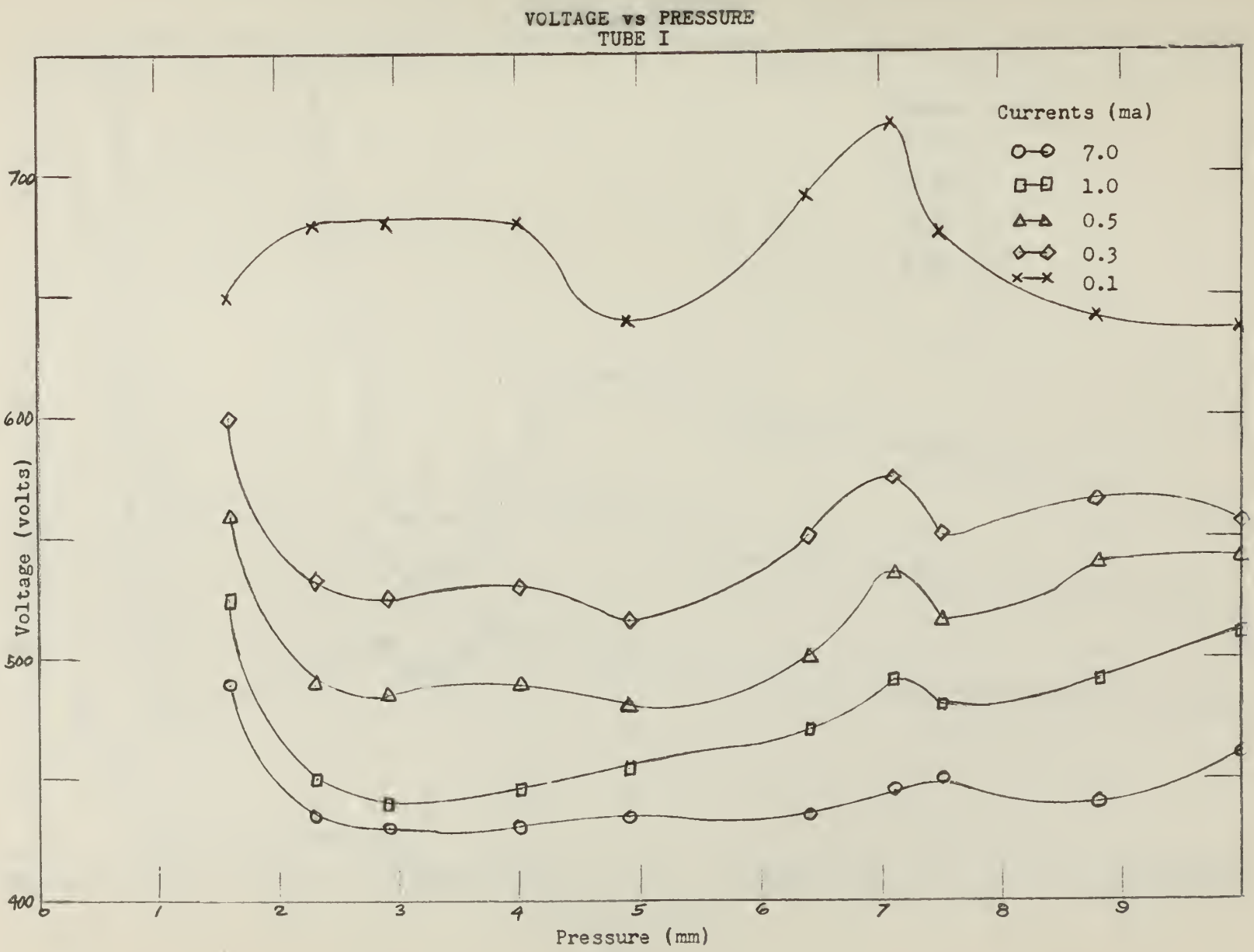

VOLTAGE vs PRESSURE
TUBE I
Currents (ma)
7.0
1.0
0.5
0.3
0.1
700
600
500
400
Voltage (volts)
0
1
2
3
4
5
6
7
8
9
Pressure (mm)

Figure 30

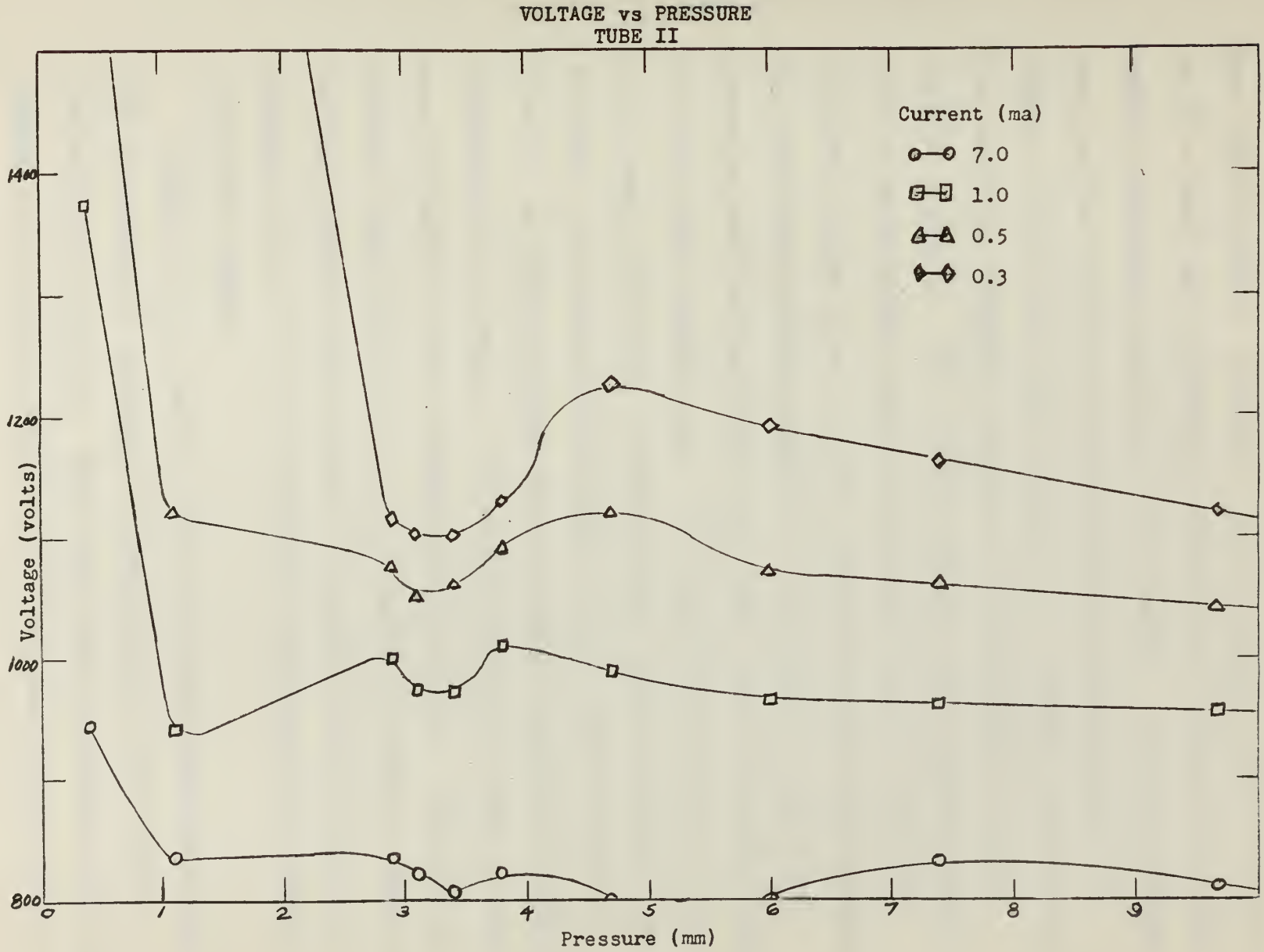

VOLTAGE vs PRESSURE
TUBE II
Current (ma)
7.0
1.0
0.5
0.3
1400
1200
1000
800
Voltage (volts)
0
1
2
3
4
5
6
7
8
9
Pressure (mm)

Figure 31

over the range of currents investigated of the voltage-pressure relationship. In tube I in the pressure area of 7.4-7.0 mm Hg a small but pronounced voltage peak occurs at all currents, increasing with decreasing current. On this pressure area is the transition from unstable to stable striation region. The 0.1 ma curve, showing the greatest fluction, is the exception changing, instead, from unstable to the no striation region. The voltage appears quite constant while passing through the center of the stable and no striation regions, though it was in this stable area that the frequency and wavelength changed abruptly. Continuing to decrease pressure sees another sharp rise; this area of pressure moves back into the unstable area. The exception is the 0.1 ma curve again, showing a decrease rather than an increase in voltage. It is noted from Figure 30 that the two dips in this 0.1 ma curve coincide with pressures having the highest discharge out currents. The striation regions seem to have some influence on the voltage characteristics. However, exceptions again appear as in previous relationships. Here we see very similar dips in the 5.0 mm area for 0.3 and 0.5 ma although one is in the no striation region and the other in the stable region.

Figure 31 for tube II points out more dramatically the dip in voltage at pressures corresponding to the highest discharge out currents. This would seem to indicate that the instabilities causing the loss of discharge at the lowest

currents may in some way effect the voltage across the tube. Note also, the much higher voltages associated with the smaller diameter tube, especially at lower pressures. Little correlation is noted at the higher pressures with the unstable-stable region boundary. A continuing gradual increase in voltage is seen throughout this area. The sharp rise is again evident as the pressure is lowered into the unstable region. Here, as with tube I, the most pronounced changes in voltage are seen with the lowest currents.

Figures 32 and 33 show the relationship of velocity and pressure. Although tube I presents a definite pattern, the area of greatest change is again shown to occur in the stable and no striation regions. Tube II shows a minimum velocity in the pressure region of the unstable-stable boundary. Only two current values, however, supplied enough points to denote the general trend. If the striations were purely acoustic waves, their velocity would be directly proportional to pressure, that is, velocity would decrease with decreasing pressure. Since for any constant value of current the striation velocity varies considerably with decreasing pressure, it is felt that the mechanism propagating moving striations is not of the same nature which propagates an acoustic wave.

The wavelength-pressure relationship is shown in Figures 34 and 35. Note the simple appearance of the tube II results compared to the larger diameter tube. In tube II a slight decrease in wavelength with decreasing pressure is seen. In

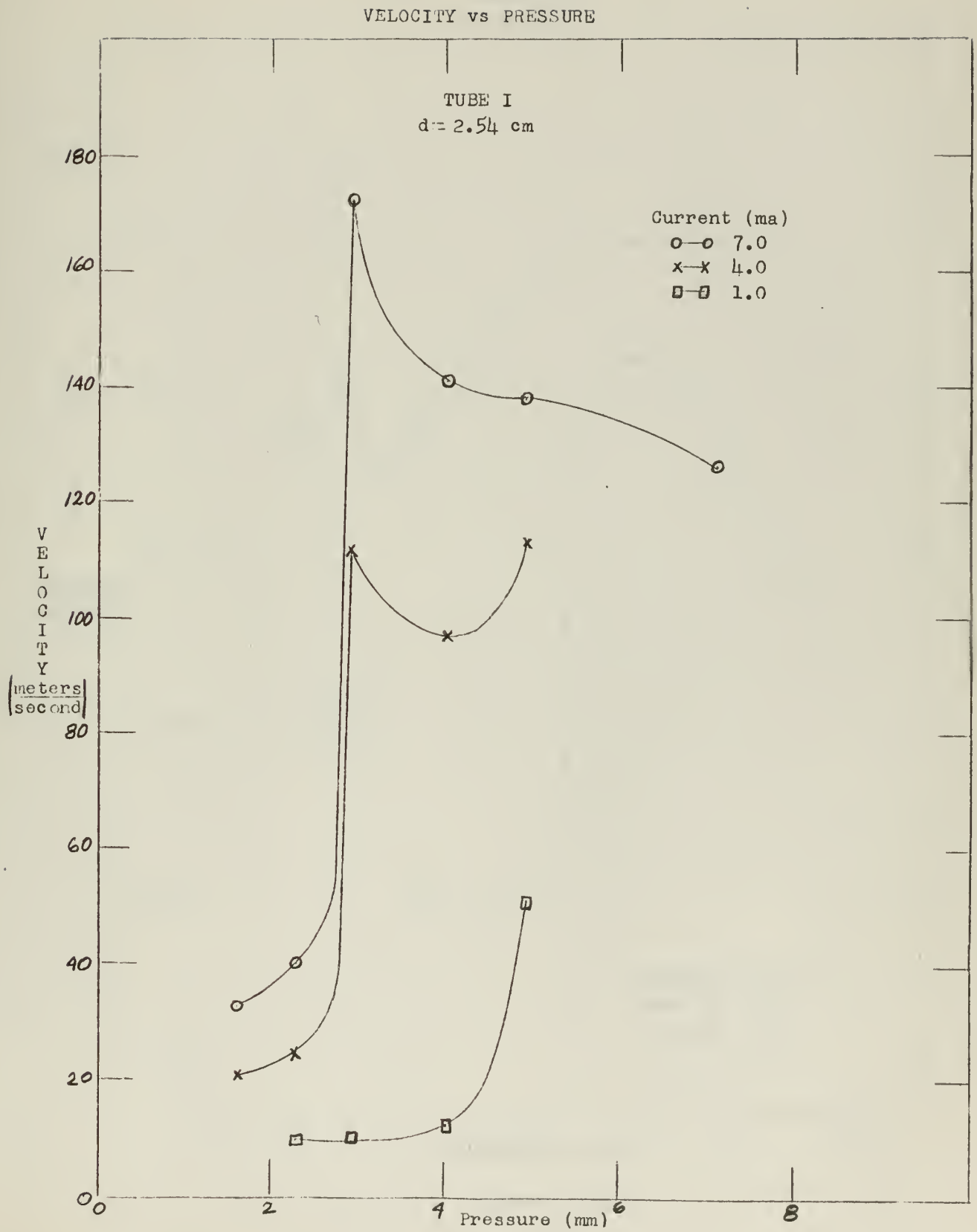

VELOCITY vs PRESSURE
TUBE I
d = 2.54 cm
Current (ma)
7.0
4.0
1.0
VELOCITY (meters/second)
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
Pressure (mm)

Figure 32

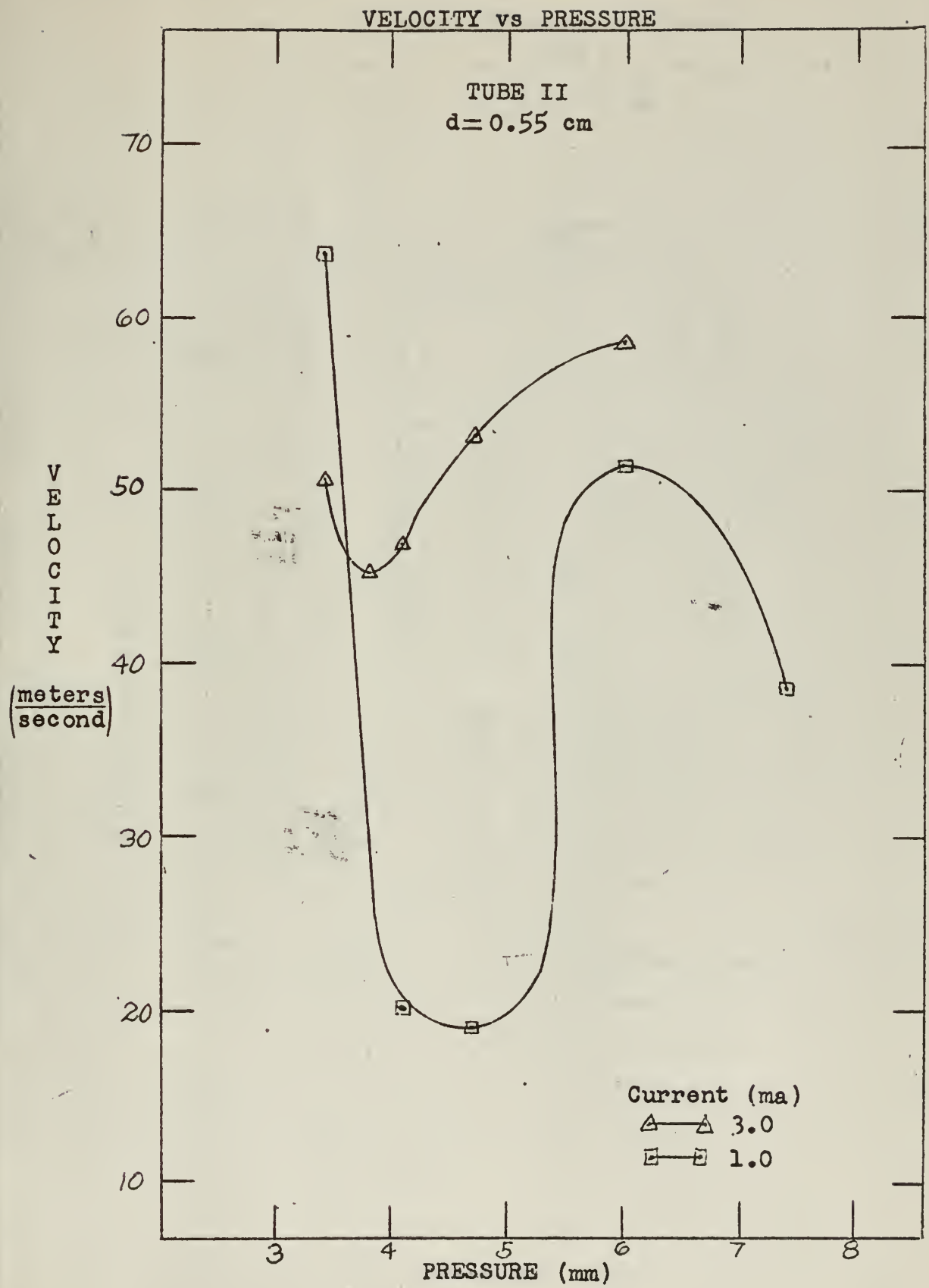

VELOCITY vs PRESSURE
TUBE II
d= 0.55 cm
70
60
50
40
30
20
10
VELOCITY
(meters/second)
3
4
5
6
7
8
PRESSURE (mm)
Current (ma)
3.0
1.0

Figure 33

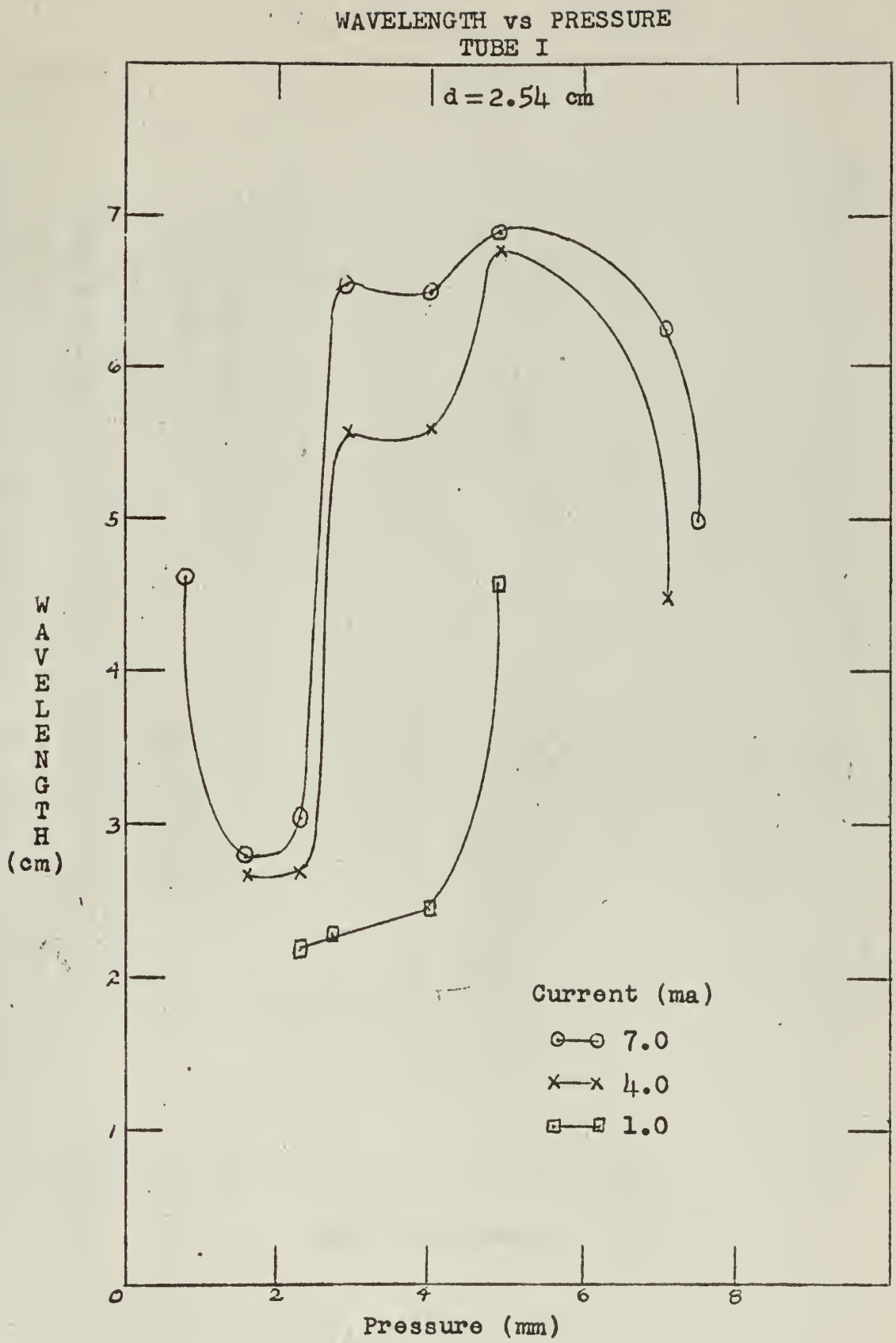

WAVELENGTH vs PRESSURE
TUBE I
d = 2.54 cm
WAVELENGTH (cm)
Pressure (mm)
Current (ma)
7.0
4.0
1.0
0
1
2
3
4
5
6
7
2
4
6
8

Figure 34

WAVELENGTH vs PRESSURE
TUBE II

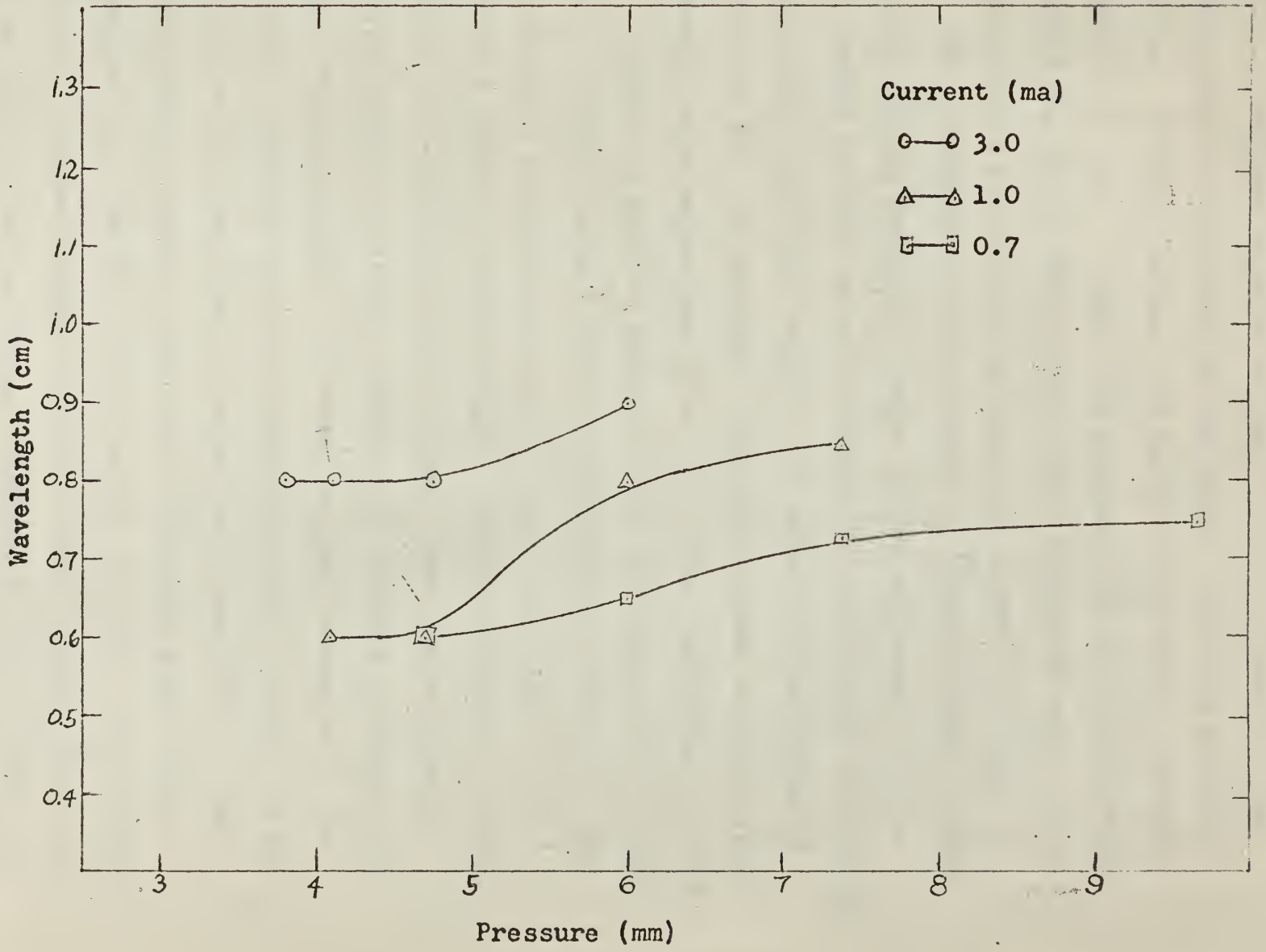


Figure 35

tube I a maximum appears at about 5.0 mm followed by the sharp drop in the center of the stable striation pressure region. An increase was seen again in the micron pressure region for 7 ma. A value 50% greater than the normal wavelengths was also found in the micron region of tube II but was a single observation and does not appear in Figure 35.

The frequency-pressure curves of Figure 36 again point out the abrupt frequency change in the mid-stable region. The maxima are also noted in Figure 37 for tube II corresponding to the mid-stable region. Not shown are the isolated points in the low pressure, low current areas at which frequencies were determined to be 5-10 times the values plotted.

Figure 38 relates distance from the cathode to the current at which the striations disappeared for tube II. The curves tend to converge at a point near the head of the positive column and the critical current varies most at distances of 5-20 cm from the cathode. Note the extremely narrow range of critical currents at constant pressure further from the cathode. As expected, the curvature of the constant pressure lines for the low critical current is opposite to that reported by Cooper and Oleson/25/ for the high critical current, since the striations again begin disappearing from the cathode end of the tube. The minimum value of critical current is reached much further from the anode than the maximum values reported in their paper. An attempt was made to obtain a similar plot for tube I, but the

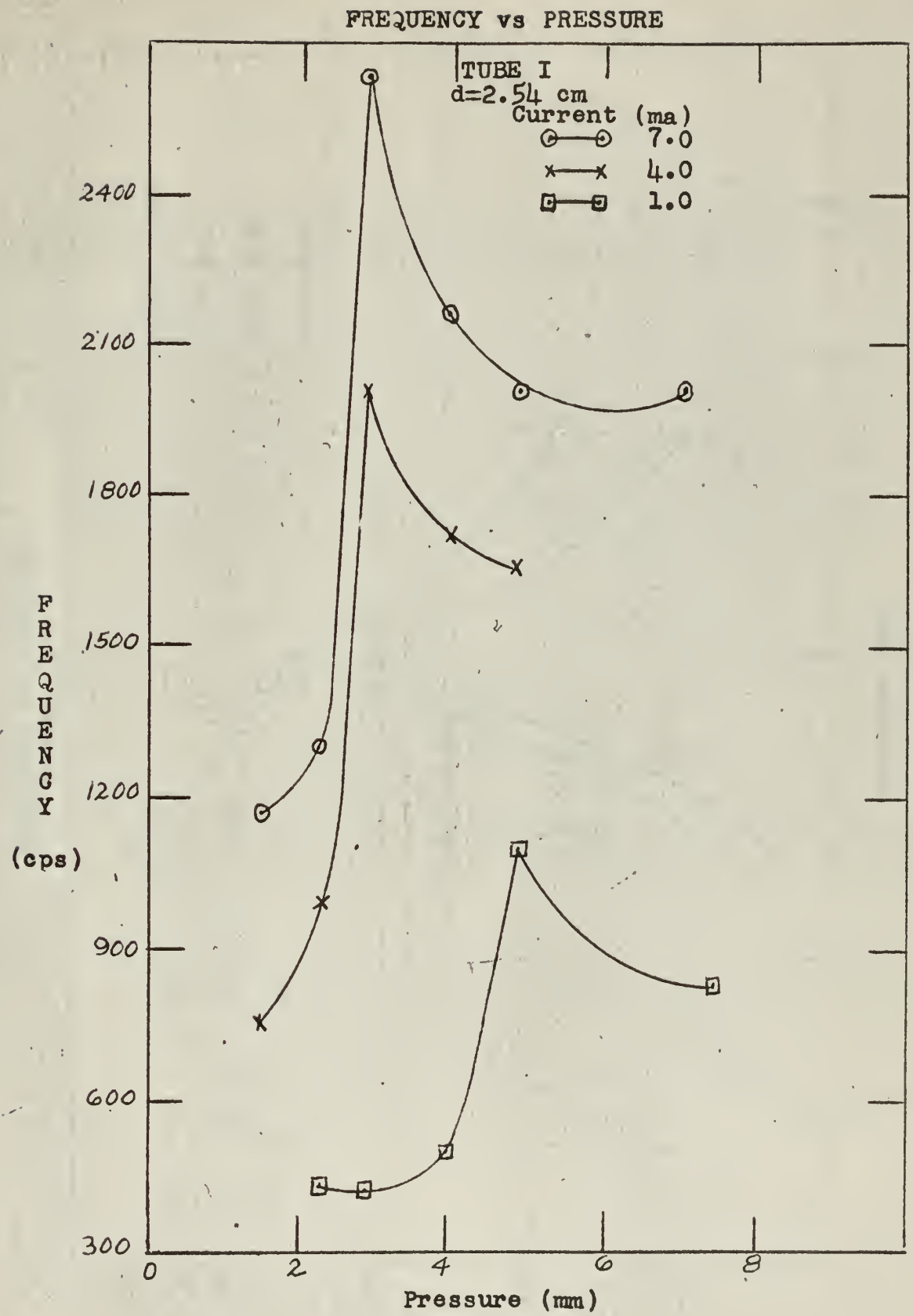

FREQUENCY vs PRESSURE
TUBE I
d=2.54 cm
Current (ma)
7.0
4.0
1.0
2400
2100
1800
1500
1200
900
600
300
FREQUENCY (cps)
0
2
4
6
8
Pressure (mm)

Figure 36

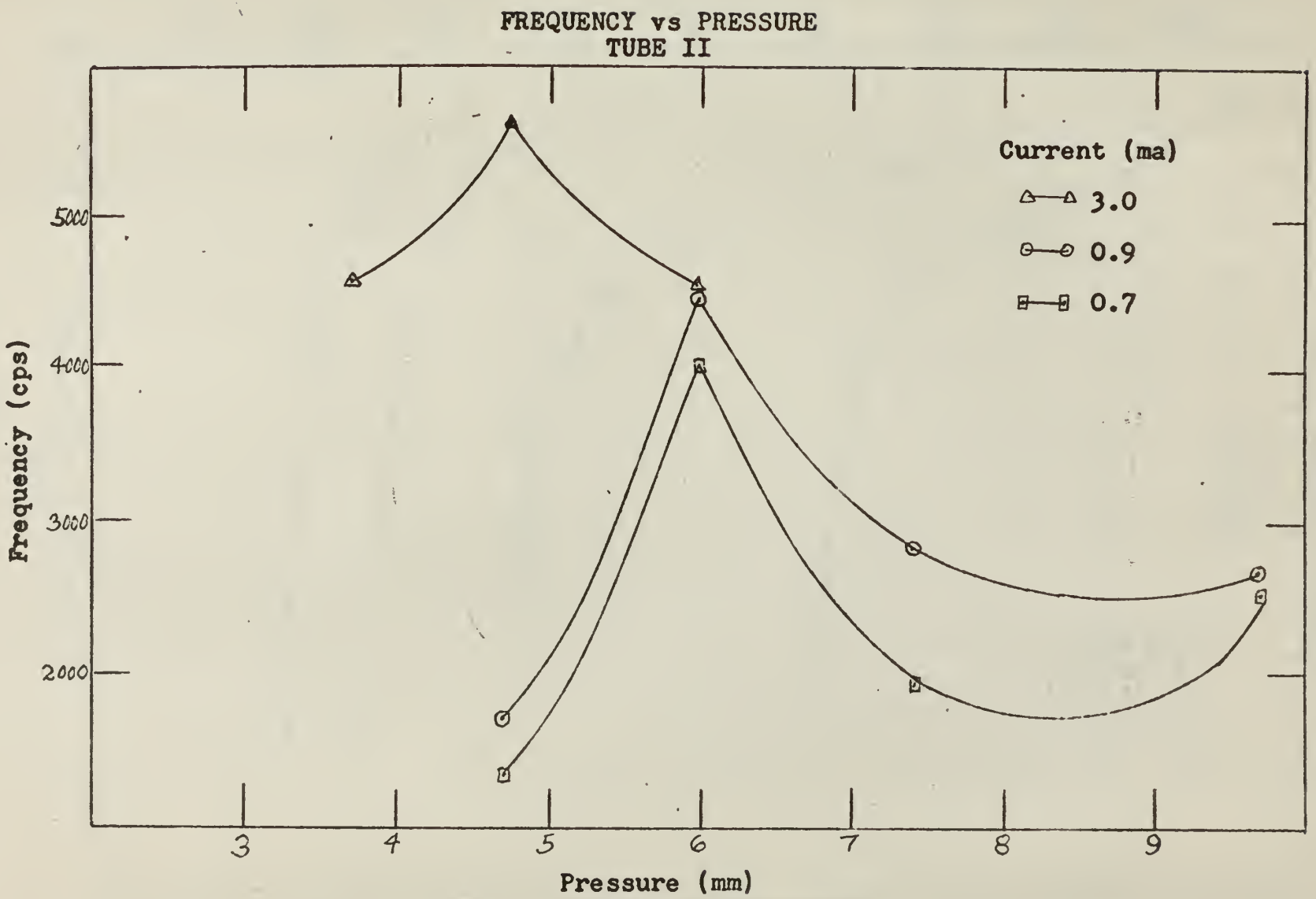
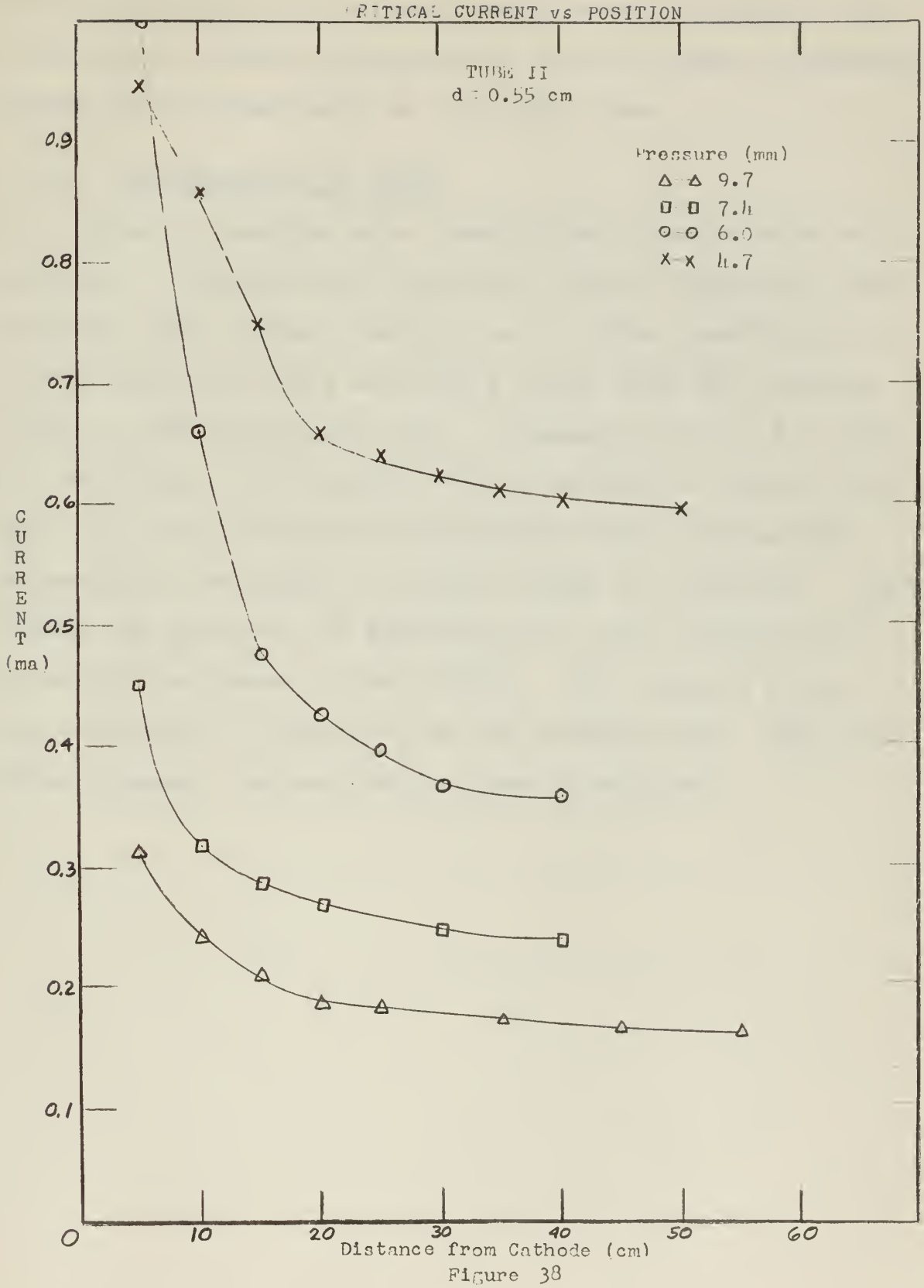

FREQUENCY vs PRESSURE
TUBE II
Current (ma)
3.0
0.9
0.7
Frequency (cps)
5000
4000
3000
2000
3
4
5
6
7
8
9
Pressure (mm)

Figure 37


CRITICAL CURRENT vs POSITION
TUBE II
d = 0.55 cm
Pressure (mm)
9.7
7.4
6.0
4.7
CURRENT (ma)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
Distance from Cathode (cm)
Figure 38

striations disappeared almost simultaneously throughout the tube, and a constant pressure plot shown to these coordinates would appear essentially as a straight line.

3.6 Investigation in Argon

Several pressures were investigated in argon with one purpose: to locate the no striation region. Although lower currents were reached than reported by other investigators, striations were always detectable either with the rotating mirror or photomultiplier tube. Pressures of 5.8, 3.0, and 1.1 mm Hg were investigated down to currents as low as 0.058 ma. At 5.8 mm, relaxation oscillations were intermittant depending on an apparent internal change of resistance. This change was noted by the appearance of a thin, glowing film covering the sleeve of the cathode. This occurred without any variation of parameters by the investigators. When this film appeared, the oscillations were eliminated.

4.0 Conclusions

Results of this investigation support Pekarek's findings of a no striation region in a low current neon glow discharge, though our limits do not agree well with those of Figure 9. Our striation free region does not begin until below currents of Pekarek's investigation. This is understandable when one realizes the effects of different electrode configurations, applied voltage, purity of the gas, and other parameters. These results do show that this absence of striations extends to currents lower than previously investigated and is not peculiar to the uniform diameter tube of Pekarek's experiment. Tube diameter is noted to effect the limits of the unstable, stable, and no striation regions, but not to radically change or completely eliminate any regions.

The fast striation pattern detected at lower currents and pressures did appear more dependent upon tube diameter. In the smaller diameter tube they were detected over a much larger region and their appearance significantly decreased the no striation region.

An abrupt change in the striation pattern in the stable striation region was observed. Frequency and wavelength changed significantly with a 1.0 ma change in current while the striation pattern itself remained extremely stable. This leads to the conclusion that even in this region, the oscillation characteristics are extremely sensitive functions of current.

Wave-like disturbances which appeared to be travelling

from cathode to anode were observed in all unstable regions investigated. Varying velocities for these waves, assuming velocities can be assigned, were observed on any one photograph. These velocities did not vary in any definite relationship with the pressure or distance from the cathode. The average velocities determined at various pressures and currents varied from less than 100 to over 1000 meters/second. These were not detected on the photomultiplier tube at any time. They do not meet the usual description of negative striations, nor do they fulfill the requirements of Pekarak's "wave of stratification" though they have some similar characteristics. They definitely do effect the striations and appear to influence their instability by causing a significant increase in the striation velocity at the point of meeting.

5.0 Recommendations

Further investigation of this low pressure, low current region should be conducted using other gases. The few pressures investigated in argon revealed no striation free region for tube diameter of 2.54 cm. The smaller diameter tube may yield different results. The use of other gases such as He and Kr may provide an answer to the influence of atomic weight on the striation regions.

Further investigation, particularly use of probe techniques, may yield more information, concerning the wave moving from cathode to anode. Other electrode configurations should be used to determine their effect upon the wave disturbances and the striation regions.

Investigation in this very low current, low pressure region in a tube comprising sections of different diameter should be considered. Use of a current pulser in the striation free region may also yield interesting results.

Further investigation of the stable region to determine why there is an abrupt change in the velocity of the striations is called for.

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